Sockeye Salmon Escapement and Mark-Recapture Studies at Larson Lake in 1997

by

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ABSTRACT

From July 21 to September 13, 1997, we operated a weir below the outlet of Larson Lake, a major producer of sockeye salmon *Oncorhynchus nerka* in the Susitna River. Daily counts of the sockeye escapement resulted in a total census of 40,282, with an estimated 55.7% (22,435) females and 44.3% (17,844) males. The mean mid-eye to tail fork length (MEF) was 493 mm (± 0.7 mm) for females and 530 mm (± 1.1 mm) for males. The escapement was dominated by age 1.2 (53.5%) and age 1.3 (36.1%) fish. The 1997 escapement was slightly higher than escapements observed in the mid 1980s, which ranged from 16,753–37,874. The ratio of Larson Lake to Yentna River (sonar-derived) escapements has remained fairly constant, suggesting that the sonar estimates can be used to index sockeye salmon escapements in the Susitna River. We also conducted a mark-recapture (M-R) experiment to assess assumptions involved in recovering tagged sockeye salmon from their spawning grounds. A constant proportion of the escapement (9.1%) was marked with spaghetti tags at the weir and 25% of these fish received a secondary jaw tag. Secondary tagging also included 250 fish fitted with a plastic-tipped dart tag. Tag recovery was conducted by beach seining the spawning grounds of Larson Lake over eight 5-day periods in six areas. Of the total sockeye escapement (40,282), 8,170 (4,429 females and 3,741 males) were caught in the spawning grounds, a capture efficiency of 20.3%. Sex composition of recaptured and untagged fish captured in the spawning grounds did not differ from the weir estimate ($P > 0.10$). However, MEF distributions of both sexes differed significantly between the weir and recovery samples (K-S test; $P < 0.01$), indicating that size selectivity occurred in the spawning ground surveys. Smaller fish were captured in the spawning grounds and the difference was more pronounced in males than females. Dual tagging experiments indicated that males lost 21% of their spaghetti tags while females lost none of their spaghetti tags. M-R estimates of the tagged proportion and capture efficiency were generally lower than the weir-derived estimates ($P < 0.05$), which resulted in an over-estimate of the escapement. For example, the M-R estimate based on all tagged fish was 56,315, which is 40% higher than the weir count. M-R estimates using dual tagged fish often increased the bias, indicating that secondary tagging affects catchability. However, after correcting for tag loss of fish without secondary tags, the M-R estimate of male escapement (18,613) was only 4.3% higher than the weir estimate. Because females had no missing spaghetti tags, the M-R estimate of 29,437 females was still 31% higher than the weir estimate. The combination of tag loss and tagging effects on catchability, which differed between males and females, resulted in a M-R escapement estimate that was biased high. Therefore, the type and method of primary and secondary tagging may be critical to the success of M-R studies if recovery sampling is conducted in spawning grounds. Our preliminary experience with dart tags suggests that they are retained as well as spaghetti tags, require minimal handling to attach, and have little affect on recapture probability. Size selectivity in the spawning ground survey indicates that stratified sampling should be used. When designing a M-R study, other types of recovery sampling should be considered, such as fishwheels or weirs.

INTRODUCTION

Management of the mixed-stock fishery in Upper Cook Inlet, Alaska (Figure 1) relies on riverine sonar to estimate adult salmon escapements in three major watersheds: the Kasilof, Kenai, and Yentna Rivers (Ruesch and Fox 1997). The primary objective of the Yenta River sonar program, which has been conducted since 1981 (Davis and King 1997), is to estimate sockeye salmon *Oncorhynchus nerka* escapements as stipulated by the Alaska Board of Fisheries. These data are used to index escapement trends in the whole Susitna River drainage. Data collected during the Susitna Hydrological (Su-Hydro) feasibility studies in the 1980s indicated that sockeye salmon escapement in the Yentna River represents a fairly constant proportion of the escapement in the Susitna River drainage (Pers. Comm., Ken Tarbox, Alaska Department of Fish and Game, oral report to the Alaska Board of Fisheries Committee, February 1998). However, a recently submitted state senate bill (SB 40) proposed that the Alaska Department of Fish and Game (ADFG) enter into discrete stock management as opposed to mixed-stock management of Upper Cook Inlet commercial fisheries. To achieve this goal, both stock and sub-stock specific escapements within Upper Cook Inlet would require evaluation.

The Susitna River watershed, which originates in the mountains of the Alaska Range about 145 km south of Fairbanks, comprises approximately 49,200 km^2. It flows southwesterly for about 400 km before entering Upper Cook Inlet west of Anchorage (Figures 1 and 2). The three largest tributaries of the Susitna drainage are the Yentna, Chulitna, and Talkeetna Rivers. Larson Lake (62°20'N; 149°53'W), at the head of Larson Creek (Figure 2), is considered the largest producer of sockeye salmon in the Talkeetna drainage. Weir counts of escapements in the mid-1980s ranged from 16,753 to 37,874 (Marcuson 1984, 1985, 1987, 1988). An estimated 520,270 fry reared in the lake in 1994 (King and Walker 1997).

This project was designed to enumerate the escapement of sockeye salmon into Larson Lake in 1997 by counting the number of fish passing a weir placed in Larson Creek. In addition, we compared Larson Lake escapements with Yentna River sonar estimates using the 1997 data and data collected in the mid-1980s. This analysis was conducted to help evaluate the Yentna River sonar estimate as an indicator of discrete stock escapements as well as an index of the total sockeye escapement in the Susitna River.

This project was also designed to assess the efficacy of using mark-recapture (M-R) techniques to estimate sockeye salmon abundance. A M-R experiment was conducted by tagging a portion of the escapement at the weir and recovering tagged fish in spawning grounds around the perimeter of the lake. We evaluated M-R assumptions required for an unbiased abundance estimate. Characteristics of fish captured in the spawning grounds were compared to fish collected at the weir to assess sampling selectivity. To evaluate the assumption of no tagging effects on catchability, we (1) compared the proportion of fish tagged at the weir with the proportion of tagged fish recaptured in the recovery survey, and (2) compared the proportion of the escapement sampled in the spawning grounds with the recapture rate of tagged fish. Dual tagging methods were used to estimate tag loss. In addition, sampling was stratified temporally and geographically to further assess the M-R methods. Finally, M-R population estimates were compared with the weir count to quantify overall bias in the M-R technique.

METHODS

Weir Operations

A weir was installed in Larson Creek on July 18, approximately 15 m downstream from the Larson Lake outlet (Figure 3). The weir was very similar to one described in Anderson and McDonald (1978) and consisted of two horizontal stringers fabricated from 7.62 cm (3-inch) aluminum angle, drilled with 3.18 cm (1¼ inch) holes on 6.35 cm (2½ inch) centers. The stringers were supported every 3 m with tripod frames constructed from heavy drill pipe – 5 cm (2 inch) × 1.8 m – with two 2 m wooden support legs. Aluminum pickets – 1.13 cm (1⅛ inch) × 1.5 m – were then fitted through the top and bottom stringers. The weir spanned the entire distance of the stream, approximately 11 m. The maximum depth of the creek at the time of installation was only 51 cm and, although flow rates were not measured, stream velocity was minimal. The streambed was composed primarily of strewn boulder which, combined with the low flow rate of the creek, made for a very stable and fish-tight weir.

A small holding area (1.8 m × 2.4 m) was constructed in front of the weir using aluminum-perforated plate. Pickets were removed from the weir to allow fish to pass either into the lake or into the holding area, where sampling for age, length, and sex (ALS), and tagging took place.

Fish were passed and counted throughout the day and into the evening until darkness. If sport fishermen or other people were observed around the weir, ADFG personnel remained on site to prevent tampering. Climatic data, including air and water high and low temperatures, cloud cover, wind direction, and approximate wind velocity were collected every 24 h.

ALS and Tagging

Every 10th fish that passed through the weir was diverted into the holding area where it was netted and identified by sex, measured mid-eye to tail fork length (MEF) to the nearest 5 mm, and fitted with at least one external tag. Every hundredth fish (1% of escapement) also had scales removed from the preferred area (Koo 1955) for age determination (Tobias et al. 1996). Physiological aberrations such as net scars or gashes as well as state of ripeness were also recorded.

All fish held for tagging received a 30.5 cm spaghetti tag (Floy® FT-4) fitted in its back near the posterior dorsal fin terminus. A stainless steel applicator was used to pull the tag through the flesh and tags were affixed using an overhand knot that was firmly cinched against the back of the fish. All spaghetti tags were sequentially numbered. The tags were also color coded to aid temporal stratification of the run. Tag color was changed after application of every 500th tag in the order orange, yellow, pink, white, green, gray, and brown.

Three different combinations of secondary tags were used to assess spaghetti tag loss: (1) every fourth spaghetti-tagged fish was fitted with a small, sequentially numbered metal jaw tag (National Band and Tag Co.®, style 681), (2) the second color group of spaghetti tags (yellow) were adipose fin-clipped, and (3) the first 250 fish of the third spaghetti tag color (pink) received a 12.5 cm sequentially-numbered dart tag (Hallprint® No. 2, plastic-tipped). Jaw tags, which were the main secondary tag, were V-shaped and affixed with a specialized pair of pliers that folded and locked the tab on one side through a hole in the other side. These tags were placed either in the back corner of the mouth or on the lower jaw near the front of the mouth. The plastic tipped dart tags were constructed from a cylindrical printed and numbered marker, molded to a plastic barbed head. After insertion with a stainless steel applicator, the tag remained embedded in the flesh. Dart tags were affixed approximately halfway between the lateral line and the posterior terminus of the dorsal fin, just posterior to the spaghetti tag insertion.

Initially weir leakage was estimated by releasing all tagged fish behind (downstream of) the weir and then identifying each tag number as it passed back through the weir. However, this procedure was abandoned after the first release group due to a few days of abnormally high water temperatures which are believed to have caused fish to perish in the first 500 m below the weir.

Tag Recovery

The perimeter of Larson Lake was divided into six geographical areas (Figure 3) that were sampled on a 5-day rotation. A 50 m × 4 m seine was used to capture fish on their spawning grounds. The seine was deployed from the bow of a 5 m (16 ft) skiff by stationing one person on the beach and backing the boat in a semi-circle around the fish and back to the shoreline. Each end of the seine was then "pursed" to the beach. The following data were recorded for each set of the net: start/stop time, area sampled, number of untagged fish, number of tagged recaptures, and the number of fish previously captured in the seine. The sex, MEF, and condition were recorded for all first-time captures of untagged fish. Fish condition consisted of noting whether it was (1) alive and not spawned out, (2) alive and spawned out, (3) dead and not spawned out, or (4) dead and spawned out. First-time captures were all marked by hole punching (regular paper punch) both the adipose fin as well as multiple punches in the caudal fin. All captured fish were inspected for the presence of one of the three tags (spaghetti, jaw, or dart) as well as noting if the adipose fin was missing. All tag numbers, colors, and types were recorded. Each captured fish was also carefully examined for the presence of holes in either its adipose or caudal fin that would identify it as previously captured, in which case it was counted but no measurements were taken. Each area was sampled until less than 10 fish were captured per set. Spawning ground surveys were terminated when capture rates of previously sampled fish exceeded 80% for three consecutive sampling periods or when the number of tagged fish captured in one sampling period from all areas was less than 30.

Data Analysis

Size and Composition

Adult sockeye salmon were sampled in proportion to the weir count – approximately every 10^{th} fish for MEF and sex, and every 100^{th} fish for age composition (scale samples). Therefore, we assumed a simple random sample for estimating mean MEF and sex and age composition of the population. Mean MEF and the variance were estimated as follows for males and females and the sexes combined:

$$\overline{MEF} = \frac{\sum_{i=1}^{n} MEF_i}{n_k} \text{ and} \tag{1}$$

$$v\left(\overline{MEF}\right) = \frac{\sum_{i=1}^{n}\left(MEF_i - \overline{MEF}\right)^2}{n_k\left(n_k - 1\right)}, \tag{2}$$

where n is the sample size of sockeye salmon collected at the weir and k indexes the group (male, female, or both). Sex and age-class proportions were estimated as follows:

$$\hat{P}_{jk} = \frac{n_{jk}}{n_j} \tag{3}$$

with variance estimate

$$v\left(\hat{P}_{jk}\right) = \frac{\hat{P}_{jk}\left(1 - \hat{P}_{jk}\right)}{n_j - 1}\left(\frac{N - n_j}{N}\right), \tag{4}$$

where j indicates either age or sex composition, k indexes the gender or age-class being estimated, n is the sample size, and N is the size of the sockeye salmon population counted through the weir.

Mark-Recapture Estimation

We used Chapman's (1951) modification of the Peterson M-R method, as described by Seber (1982), to estimate sockeye salmon escapement:

$$\hat{N} = \frac{(m_1 + 1)(n_2 + 1)}{(m_2 + 1)} - 1 \tag{5}$$

with variance estimate (Seber 1970)

$$v\left(\hat{N}\right) = \frac{(m_1 + 1)(n_2 + 1)(m_1 - m_2)(n_2 - m_2)}{(m_2 + 1)^2(m_2 + 2)}, \tag{6}$$

where $\hat{N}$ is the estimated abundance of adult sockeye salmon on the spawning grounds, m_1 is the number of adults tagged at Larson Creek weir, n_2 is number of sockeye salmon inspected for tags on the spawning grounds, and m_2 is the number of fish with tags collected on the spawning grounds. In addition to estimating the population abundance using a single M-R experiment, we computed separate estimates for males and females and applied the method to various subsets of the data (e.g., fish without secondary tags). We also defined the following:

$$\hat{P} = \frac{m_2}{n_2} \text{ and} \tag{7}$$

$$\hat{E} = \frac{m_2}{m_1}, \tag{8}$$

where $\hat{P}$, the proportion of tagged fish in the recovery survey, is the estimate of the proportion of tagged fish in the sockeye population

$$P = \frac{m_1}{N}. \tag{9}$$

The recapture rate, $\hat{E}$, is the estimate of capture efficiency or proportion of the population captured in the spawning grounds

$$E = \frac{n_2}{N}. \tag{10}$$

These variables were used to help assess M-R assumptions.

Mark-Recapture Assessment

The following assumptions were necessary for an unbiased M-R estimate of the abundance of adult sockeye salmon population passing the Larson Creek weir:

1. (*a*) all sockeye salmon have an equal probability of being tagged at the weir, *or* (*b*) all sockeye salmon have an equal probability of being inspected for tags in the spawning grounds, *or* (*c*) tagged fish mix completely with untagged fish between sampling events;
2. the population is closed, therefore the total escapement is constant;
3. all tags are reported on recovery in the second sample;
4. tags are not lost between sampling events; and
5. tagging does not affect the catchability of the fish.

We believe that assumption 1*a* was satisfied because tagging was conducted in proportion to the run and there was no indication that subgroups of the population were systematically missed. If 1*a* is true, constant proportions of tagged fish would be expected among sampling areas and periods, and between males and females. Chi-square tests ($\alpha = 0.05$) were used to test these hypotheses. However, these analyses do not necessarily preclude differential effects of tagging among strata; therefore, the hypothesis of random tagging could not be explicitly tested. Given that assumption 1*a* is true, assumptions 1*b* and 1*c* were not required for an unbiased abundance estimate. However, to assess potential selectivity in the spawning ground survey we compared sex composition and MEF distributions between the first (weir) and second (lake survey) sampling events. Specifically, we compared (1) weir samples and untagged fish sampled in the spawning grounds and (2) non-recovered tagged fish and recaptured (tagged) fish. Chi-square tests were used to test the hypothesis of no difference in the proportion of males or females. MEF cumulative distributions were compared using the Kolmogorov-Smirnov (K-S) two-sample test and means were compared using two-sample *t*-tests or analysis-of-variance (ANOVA). Rejection of the hypotheses of no difference in length frequency distributions would indicate size selectivity in the spawning ground survey.

Assumption 2 was satisfied because sockeye salmon entering Larson Lake had no other means of doing so than by passing through the Larson Creek weir, which was intact and fish-tight throughout the recruitment period. Field crews were instructed to carefully inspect all fish caught in the recovery surveys for the presence of tags (assumption 3).

Tag loss (assumption 4) was evaluated using dual tagging methods as described by Seber (1982). The proportion of lost spaghetti tags (the primary mark) was estimated as

$$\hat{P}_A = \frac{m_B}{m_B + m_{AB}}, \tag{11}$$

where $\hat{P}_A$ is the estimated proportion of lost spaghetti tags, m_B is the number of dual tagged fish in the recovery sample with a secondary tag (usually a jaw tag) only, and m_{AB} is the number of dual tagged fish in the recovery sample with both tags present. The number of recaptured fish (dual tagged initially) was then estimated as

$$\hat{m}_2 = (m_A + m_{AB})(m_B + m_{AB})/m_{AB}, \tag{12}$$

where m_A is the number of dual tagged fish in the recovery sample with a spaghetti tag only. To estimate N after accounting for tag loss, $\hat{m}_2$ was substituted for m_2 in equation 5 and m_1 was defined as number of dual tagged fish. Tag loss was estimated separately for males and females. The above method was also applied to estimate loss of jaw and dart tags. A correction for tag loss was also applied to fish fitted with primary (spaghetti) tags only:

$$\hat{m}_2 = \frac{m_2}{\left(1 - \hat{P}_A\right)} \tag{13}$$

where $\hat{m}_2$ was used in equation 5 and m_1 was defined as the number of fish spaghetti tagged only. This approach eliminated potential effects of the secondary tag on catchability while still accounting for loss of the primary tag.

Tagging may cause increased mortality or modify fish behavior compared to unmarked fish (assumption 5). If assumptions 1–4 are satisfied (or corrected for, as in the case of assumption 4) and the proportion of tagged fish in the recovery sample differs from the proportion of fish tagged at the weir (P), then the assumption of no tagging effects has been violated. We computed 95% and 99% confidence intervals to test the null hypothesis of no difference in the proportion of tags in the recovery sample and the known proportion of fish tagged at the weir. In the case of male and female tagged proportions, which were estimated at the weir, 2-sample *t-tests* were performed. A similar approach was used to assess the tag recovery rate, which estimates the proportion of the population sampled in the spawning grounds (E). We also used a chi-square test ($\alpha = 0.05$) to test for consistency in the recapture rate of tagged fish by tagging order (color group). Confidence intervals for the estimate of N, uncorrected and corrected for tag loss, were also computed. These analyses were applied separately to males and females, all tagged fish, dual tagged fish, and fish with spaghetti tags only.

RESULTS

The Weir

From July 21 to September 13, 40,282 adult sockeye salmon were counted through the Larson Creek weir (Table 1). Daily and cumulative counts are shown in Figure 4. Spaghetti tags were fitted on 3,663 fish (9.1%) – 2,040 females and 1,623 males. Of these, 919 (2.3%) – 503 females and 416 males – were also jaw tagged; 500 (1.2%) – 233 females and 267 males – were adipose fin clipped; and 250 (0.6%) – 126 females and 124 males – were dart tagged. Of the fish tagged, 2,164 (5.4%) – 1224 females and 940 males – were fitted with only a spaghetti tag. Other salmon species counted included 391 (141 through the weir, 250 behind the weir) coho salmon *Oncorhynchus kisutch* and 3 chum salmon *Oncorhynchus keta*. The sex was determined and MEF measured on 3,743 fish (9.3% of the escapement). An estimated 55.7% (22,435) of the total weir count were females and 44.3% (17,844) were males (Table 2). Mean MEF was 493 mm for females and 530 mm for males (Table 2). Scales were read on a sample of 357 fish to estimate age structure. The escapement was dominated by age 1.2 (53.5%) and age 1.3 (36.1%) fish (Table 3).

From July 28–30 we recorded water temperatures in Larson Creek that were 26°C or higher, which very likely led to the deaths of nearly 1,000 fish in a 500 m stretch below the weir. Dissolved oxygen ranged from 8.1–8.7 mg/l, which is $\geq$99% saturation at 26°C (Koenings et al. 1987) and therefore did not appear limiting. Burrows (1963) reported that mortality rates of sockeye salmon in the Fraser River were as high as 86% when water temperatures exceeded 22°C. We observed that fish milling in the warmer water below the weir appeared lethargic, but increased their activity after swimming into the cooler lake water. Therefore, we removed several large rocks from behind the weir to increase the depth, thus allowing fish to swim to the weir and hold prior to passing through. Because of the elevated water temperatures we discontinued the weir leakage experiment.

The Yentna River sonar program has been conducted since 1981 (Davis and King 1997). From 1984 to 1987 an adult weir was operated by Cook Inlet Aquaculture Association (CIAA) at Larson Lake to enumerate the sockeye salmon escapement (Marcuson 1984, 1985, 1987, 1988). Figure 5 shows the relationship between Yentna River escapement estimates (sonar) and Larson Creek weir escapements (1984–1987 and 1997). Although based on a small sample size ($n = 5$), the linear association between the sonar estimate and the weir count was relatively strong ($r^2 = 0.65$; $P = 0.099$). The estimated escapement of sockeye salmon in the Yentna River in 1997 was

157,797 (Davis 1998). The Larson Lake escapement was therefore 25.5% of the Yentna River escapement estimate. This ratio is similar to those observed in the mid 1980s: 24.6% in 1984, 35.4% in 1985, 35.1% in 1986, and 25.4% in 1987.

Tag Recovery

Spawning ground tag recovery surveys were conducted from August 21 to September 27 during eight 5-day sampling periods from the six geographical areas (Figure 3, Table 4). Adult sockeye salmon captures from all periods and areas totaled 9,814, with 8,170 (83.2%) first-time captures and 1,644 (16.8%) previously captured fish. The proportion of the escapement that were first-time captures (E) was 20.3%. Of these captures, 4,429 were females and 3,741 were males, capture efficiencies of 19.7% and 21.0%, respectively. First-time captures composed the majority of the spawning ground surveys until the final sampling period when about 46% of the fish had been caught previously. Of the 3,663 fish spaghetti tagged at the weir (2,040 females and 1,623 males), 285 (14.0%) females and 245 (15.1%) males were recaptured in the spawning ground surveys. Of the 919 jaw (+ spaghetti) tagged fish (530 females and 416 males), 53 females (10.5%) and 53 males (12.7%) were recovered. Of the 250 dart (+ spaghetti) tagged fish (126 females and 124 males), 16 (12.7%) females and 22 (17.7%) males were recovered. Of the 2,164 fish (1224 females and 940 males) fitted with spaghetti tags only, 216 (17.6%) females and 177 (18.8%) males were recovered.

Sampling Selectivity

Females composed 54.4% and males 45.6% of the untagged first-time captures of sockeye salmon in the spawning grounds, which did not differ significantly ($P > 0.05$) from the weir sample (Table 5). However, untagged females had a mean MEF of 485 mm while males had a mean MEF of 511 mm, both of which were significantly ($P < 0.001$) less than mean MEF estimates from the weir (Table 5). Figure 6 presents box plots of MEF for males and females in each spawning ground area compared to mean MEF estimates from the weir. For both sexes and all areas, mean MEF was significantly ($P < 0.01$) less than the weir estimate. Figure 7 compares cumulative MEF distributions between the weir and spawning ground samples (all areas and periods pooled). Results of K-S tests indicated that the MEF distributions differed significantly for both sexes ($P < 0.001$), although females appeared more similar than males.

Table 6 compares tagged fish that were not recaptured with tagged fish recaptured in the spawning grounds. Analyses were conducted for all tagged fish and those fitted with a spaghetti tag only. Results were similar between the two groups. Sex composition did not differ significantly ($P > 0.10$) between tagged and recaptured fish. Mean MEF of females also did not differ significantly ($P > 0.10$) between tagged and recaptured fish. However, mean MEF of recaptured males was significantly less ($P < 0.001$) than male fish that were not recaptured. Figure 8 compares cumulative MEF distributions of all tagged and recaptured fish. K-S test results indicated that the MEF distributions differed significantly for both sexes, although females ($P = 0.007$) were more similar than males ($P < 0.001$). Similar results were obtained for fish fitted with spaghetti tags only (Figure 9).

Mark-Recapture Statistics

The proportion of tagged fish recovered in the spawning ground surveys, $\hat{P}$, is presented in Table 7. Temporal and spatial differences in the tagged proportion were detected for both sexes and in the total catch. However, after removing period 3 from the analysis, no temporal effects were detected ($P > 0.05$). Similarly, after removing Inlet samples from the analysis, no spatial effects were detected ($P > 0.05$). For fish fitted with spaghetti tags only (Table 8), the only differences detected were among periods for females ($P = 0.009$); removal of period 3 from this analysis resulted in a non-significant difference ($P = 0.07$).

The recapture rate of tagged fish, $\hat{E}$, summarized by tag color is shown in Table 9. Results of chi-square tests indicated no overall effect of tagging order on the recapture rate of females, males, or both sexes ($P > 0.05$). Also, the recapture rate did not differ significantly between males and females ($P = 0.31$). Similar results were obtained for fish fitted with spaghetti tags only (Table 10).

Results of the tag loss experiments are given in Table 11. Estimated total loss of spaghetti tags was 10.6%. However, all spaghetti tag losses occurred in male fish, which lost an estimated 21.0% of their tags. Of the 13 tag losses recorded, only 5 were detected from the 919 fish with secondary jaw tags while 8 were from the 250 fish with dart tags. Also, these 5 jaw tags were positioned on the lower jaw (none were mouth corner positioned). Estimated loss of jaw tags was similar between males and females and totaled 9.9%. However, only 2 of the 10 missing jaw tags were lower jaw positioned. Although the sample size was small, dart tag loss was estimated at 10.6%. The proportion of dual tagged fish in the spawning ground survey, adjusted for tag loss, underestimated the proportion of fish dual tagged at the weir for the 3 types of tags used in the study.

Table 12 compares M-R estimates of P (proportion of tagged fish in the population) and E (proportion of the population sampled in the spawning grounds) with (1) known values of P and E based on the weir count of the total escapement or (2) separate estimates of P and E for males and females using sex composition estimates from the weir sample (see Table 2). Results are given for all tagged fish, spaghetti tagged only fish, and dual tagged fish (all dual, all jaw, lower jaw, and dart tagged). Confidence intervals (95%) indicated that the M-R estimates were significantly less than the known values of P and E for the total sockeye escapement ($P < 0.05$ for all tag groups). Similarly, *t-tests* indicated that M-R estimates of P and E for females were significantly less than the weir-derived estimates ($P < 0.05$ in all cases). For males, *t-tests* indicated that estimates of P and E were significantly lower ($P < 0.05$) than weir-based estimates for all tag groups except lower jaw and dart dual tagged.

Figure 10 compares M-R escapement estimates of the six tag groups of female sockeye salmon with the weir-derived estimate. In all cases M-R estimates of female escapement were significantly greater than the weir-derived estimate (*t-tests*, $P < 0.05$), which was expected since P and E were consistently underestimated (see Table 12). Figure 11 compares M-R escapement estimates of the six tag groups of male sockeye salmon with the weir estimate. The M-R estimates of males were significantly greater than the weir estimate (*t-tests*, $P < 0.05$) for all tag groups except lower jaw and dart tagged. For both sexes the difference in abundance estimates between all tagged and spaghetti tagged only fish can be attributed to the effects of dual tagging – particularly jaw tagging in the mouth corner – on the probability of recapture. For the total escapement (Figure 12), dual tagging with jaw tags resulted in the most severe over-estimate of the abundance (74%), while spaghetti tagging only and dual tagging with dart tags resulted in the smallest over-estimate (about 30%).

Table 13 presents the effect of correcting for tag loss of fish fitted with spaghetti tags only on M-R point estimates of the escapement; results are given for all secondary tags, all jaw, lower jaw, and dart tags. The correction was not possible for female fish (none were found with missing spaghetti tags). However, correcting for tag loss in males resulted in escapement estimates that were close to the weir-derived estimate of 17,843 male sockeye (see Table 13). M-R estimates of the total sockeye salmon escapement were still higher than the weir census because of the effect of over-estimating female escapement.

DISCUSSION

The Weir

The 1997 Larson Lake weir project provided the first sockeye salmon escapement data collected in this major tributary of the Talkeetna River in 10 years. The total escapement of 40,282 was slightly higher than escapements recorded in the mid 1980s: 35,254 in 1984, 37,874 in 1985, 32,322 in 1986, and 16,753 in 1987 (Marcuson 1984, 1985, 1987, 1988). The escapement was dominated by fish that reared one year in freshwater (90%; Table 3), which is similar to previous years: 97% in 1984, 67% in 1985, 95% in 1986, and 94% in 1987.

The Larson Creek weir counts were moderately correlated with escapement estimates from the Yentna River sonar program (Figure 5), which suggests that the sonar estimate indexes sub-stocks, therefore the total escapement, of sockeye salmon in the Susitna River. Alternatively, this suggests that weir counts of major spawning tributaries can be used to index the total escapement of sockeye salmon in the Susitna drainage.

Although we abandoned the weir leakage experiment because of high water temperatures, we believe that weir leakage was highly unlikely. We experienced none of the problems typical of other weir projects. The outlet of Larson Lake is quite shallow with minimal flow and has as an excellent substrate (strewn boulder) for operating a weir. No problems with bears were encountered and stream velocities never posed even a minor threat to weir stability.

Tagging and Recovery

Other than the initial problem with high water temperatures, the tagging phase of the study went smoothly and the goal of (spaghetti) tagging in proportion to the daily escapement was easily met. Tag recovery in Larson Lake was relatively simple because there is only one spawning tributary feeding the lake where fish were captured as they held in shallow water before entering the stream. The majority of spawning took place in shoals on the northern and eastern shoreline, areas that were easily accessible to beach seining. This allowed us to sample more than 20% of the total escapement, which is probably quite high for a M-R study.

Our data indicated that only a small segment of the spawning population was available for capture during any single time period. Captures of previously sampled fish never exceeded 20% until period 6 and exceeded 45% only in the last (8^{th}) sampling period, which was shortened to two days. This suggests a pattern of fish moving into the spawning grounds for a relatively short period of time, dying, and then being replaced by new spawners moving in from deeper areas of the lake. This cycle of spawner replacement continued throughout the entire season and is important not only for M-R studies, but for fishery managers who rely on aerial counts of spawning grounds for escapement information. Quinn and Foote (1994) looked at how body size and sexual dimorphism of sockeye salmon in Iliamna Lake influenced reproductive success. They reported that mortality rates of males and females were similar but females remained on the spawning grounds slightly longer than males – 7.4 days versus 6.8 days. If spawning takes place over a period of about six weeks, it is likely that only 15–20% of the population would be available for capture or counting at any point in time.

The rationale for using jaw tags as the (main) secondary mark was that they are not easily shed since they are small and not external to the body. Other studies have shown that jaw tag losses are minimal (MacCrimmon and Robbins 1979; Slatick 1976). Initially we placed the jaw tags in the back corner of the mouth; however, we noted that this placement partially restricted mouth closure. Therefore, placement of the tag was moved forward in the mouth, on the lower jaw of each fish. This placement did not appear to interfere with mouth closure, but the tag was now perpendicular to the lower jaw, possibly making it more susceptible to snagging in the seine. One unexpected result of using jaw tags was that 5 spaghetti tags were counted as missing due to the presence of a jaw tag, while 10 jaw tags were missing based on spaghetti tag recoveries. These results suggest that jaw tags are not as reliable as initially assumed, although this may not necessarily be the case. Seining crews were instructed to observe all fish for the presence of tags, but it is possible that some jaw tags reported as missing went unobserved. In one instance a spaghetti-tagged fish was captured and no jaw tag was recorded. A few days later the same fish was captured again, but this time a jaw tag was observed. Therefore, it is possible that some jaw tags were incorrectly reported as missing. We also found that only 2 of the 10 jaw tags reported as missing were positioned on the lower jaw. These tags were more visible and thus easier to observe. Furthermore, it is quite possible that the 2 missing lower jaw tags may have been pulled out by the seine. This occurred in one set when a jaw tag (with tissue attached) was found in the seine and matched to a fish that was bleeding in the mouth where the tag had recently pulled loose. Furthermore, if some jaw tags were not detected it is likely that spaghetti tag losses were underestimated. Only 5 of the 13 observed spaghetti tag losses were attributed to the 919 fish with jaw tags, while 8 were from the 250 fish with dart tags. These 5 jaw tags were all positioned on the lower jaw (none in the mouth corner). Dart tags were easier to detect than jaw tags and thus we believe that this disparity indicates that some spaghetti tag losses were missed because of unobserved jaw tags, particularly those in the mouth corner.

All 13 spaghetti tag losses were attributed to male fish, while dart and jaw tag losses occurred in both males and females (Table 11). McPherson et al. (1997) also found that spaghetti tag losses from medium-sized chinook salmon *Oncorhynchus tshawytscha* were unique to males. This anomaly may be related to sexual dimorphism of male salmon at maturity. Male sockeye develop an exaggerated dorsal hump, which may hasten tag loss. We tagged the majority of our fish in bright or semi-bright condition before the humps formed. Therefore, as the hump became more prominent, spaghetti tags that were tightly cinched against the fish back could have torn loose. Another viable explanation involves behavioral patterns exhibited by spawning males. Schroder (1981), Fleming and Gross (1994), and Quinn and Foote (1994) reported that rigorous intra-sexual spawning competition occurs between males for access to ripe females. It is plausible that spaghetti tags were pulled out of male sockeye by the protruding teeth in the elongated snouts of other males defending females. Field crews found spaghetti tags lying on the lake bottom with broken loops, suggesting that these tags had been torn loose. However, other tags were found with the loop intact, perhaps from tags that had been placed too high in the back, allowing them to pull out. Physiological changes and behavioral aspects may have worked in concert to cause the observed spaghetti tag losses in males only.

The primary reason that we used dart tags in this study was to evaluate them for possible use as a primary tag in future M-R studies. Dart tags have a barbed plastic-tipped head that is designed to penetrate the flesh and slide over and lock behind internal fin spines. Even though these tags are not designed specifically for salmon, they performed well, particularly in terms of ease and speed of application. Although the recovered sample size was small (n = 38), tag loss was similar to both spaghetti and jaw tags (Table 11). Furthermore, recovery rates of dart tagged fish were only slightly less than fish with spaghetti tags only, indicating that effects of dart tags on catchability were minimal (Table 12). Because dart tags can be applied quickly and are less susceptible to being torn out by other fish or overhanging debris, they appear to be a good candidate for salmon M-R studies. Butler and Loeffel (1972) concur with this assessment in their comparison of anchor (dart) and spaghetti tags on coho and chinook salmon. In their study spaghetti tags losses were less than dart tag losses, but the advantages dart tags provided in reduced handling outweighed the difference in tag retention. Other studies have reported different tag loss results. McGlennon and Partington (1997) found shedding rates of dart tags to be markedly higher than loop (spaghetti) tags in aquarium-reared sparid snapper *Pagrus auratus*. However, Sprankle et al. (1996) found that shedding rates of dorsal loop tags (tied in an overhand knot) were four times higher than dart tags in striped bass *Morone saxatilis*. Timmons and Howell (1995) reported similar numbers of spaghetti and dart tags retained in both catfish *Ictalurus spp.* and buffaloes *Ictiobus spp.* The species of fish and the time required for a tagged fish to be recaptured both play an important role in deciding which tag to use. If visual surveys of tagged fish are part of the study design, spaghetti tags may be the better choice because they are visible from both sides of the fish (Timmons and Howell 1995); although, dart tags can be applied to both sides of the fish. Finally, if increased predation of tagged fish is a concern, we found that brown colored spaghetti tags were very difficult to see. Therefore, the choice of tag color may be an important consideration, especially if tagging increases the likelihood of predation.

The final dual-tagging method used in our study involved 500 spaghetti tagged fish that were adipose fin-clipped. This technique revealed three spaghetti tags losses, but we decided not to use these data because the sex of these fish was unknown and the method was generally unreliable. We used a paper punch to mark the adipose fins of every fish captured in the spawning ground surveys to identify previously sampled fish. We found that holes in the adipose fin apparently induced "fin-rot" on some fish, to the point where the fin completely deteriorated. These fish could have been confused with those adipose fin-clipped at the weir and misidentified as a fish missing a spaghetti tag. Therefore, we began hole-punching caudal fins. We recommend that researchers do not hole-punch adipose fins of salmon if recoveries are conducted in spawning grounds.

Mark-Recapture Estimation

Perhaps the most important objective of this study was to assess M-R assumptions. Specifically, we sought to evaluate spaghetti tagging and spawning ground recovery sampling, methods that have commonly been used to estimate salmon abundance in Alaska (e.g., Thompson et al. 1986; Pahlke and Bernard 1996). Performing the M-R study together with the weir program allowed us to explicitly assess M-R assumptions and identify sources of bias in the M-R estimate. The weir program allowed a high degree of control over tagging with no known sources of sampling bias (assumption 1*a*). The weir also provided a census of the total escapement, which was closed to recruitment (assumption 2), and precise estimates of the sex composition, size (MEF), and age structure of the population. These features of the study allowed us to assess selectivity in spawning ground surveys (assumption 1*b*). Dual tagging (assumption 4) provided a method of correcting for tag loss and therefore allowed an evaluation of tagging effects on catchability (assumption 5). We believe that assumption 3 (reporting of all tags recovered) was for the most part satisfied, although, as discussed previously, there was an indication that some jaw tags (especially those placed in the mouth corner) may not have been reported. We attempted to circumvent this problem by analyzing subgroups of tagged fish.

Sex composition in the spawning ground (recovery) surveys of tagged and untagged fish did not differ from the weir sample. However, size selectivity occurred in the recovery survey and was more pronounced in male than female fish (see Tables 5–6 and Figures 6–9). This problem could result in a biased M-R estimate, particularly if the first sampling event (tagging) is not random, which is often the case (although not in our study) and random mixing of tagged and untagged fish does not occur between sampling events. These results indicate that stratified sampling methods should be used and that the strata could be defined by sex (minimally) or size groups within each sex. Seber (1982) recommends using different capturing methods in the first and second sampling events to help reduce bias from non-random sampling.

The proportion of tagged fish in the recovery surveys was somewhat inconsistent among periods (Table 7). Although, this was due to high proportions of tagged fish captured in period 3 (9/02 to 9/06) in all areas except the outlet and southeast beach (see Table 4). We also found somewhat inconsistent proportions of recovered tags among areas (Table 7). This was due to high proportions of tagged fish captured in the Inlet, except after period 4 when only 17 fish were caught in this area (see Table 4). A similar analysis that did not include dual tagged fish (spaghetti tagged only) resulted in more consistent tagged proportions, although females exhibited a minor inconsistency related to period 3 (Table 8). Given that a random sample of fish were tagged at the weir (assumption 1*a*), these results suggest a differential effect of tagging on capture probability; in particular, dual tagging may have compounded this problem. On the other hand, recapture rates based on tagging order (color groups) were fairly consistent (Tables 9 and 10) indicating that run timing did not affect the probability of recapture. We concluded that, overall, the inconsistencies discussed above were relatively minor, therefore recovery data for the majority of the analyses was pooled.

Fish marked with spaghetti tags only had a higher overall recapture rate than all tagged fish – 15.4% versus 14.5% – indicating that dual tagging decreased the probability of recapture (Tables 9 and 10); this was particularly evident with jaw tagged fish (Table 12). Subsequently, dual tagging generally increased the difference between the M-R abundance estimate(s) and the weir count (Figure 12), even after correcting for tag loss. However, these results depended on the type of secondary tag used, especially for male fish (see Figures 10 and 11). Dual tagged males with secondary dart tags, for example, gave an escapement estimate that did not differ significantly from the weir-derived estimate. Presumably this was because correcting for tag loss was much more important than tagging effects on catchability (which was probably minimal in this case).

To eliminate effects of secondary tags on recapture probability, we applied tag loss estimates to fish that were spaghetti tagged only (Table 13). This was done for males only because female sockeye were not observed with missing spaghetti tags. Therefore, females that were spaghetti tagged only still gave a M-R escapement estimate that was 31% higher than the weir-derived estimate. The effect on escapement estimates of males, however, was substantial. Without correcting for tag loss, the M-R point estimate was 32% higher than the weir-derived estimate of 17,843 male sockeye (Figure 11). After applying tag loss corrections based on all secondary tags (jaw + dart) and lower jaw tags, escapement estimates were very close to the weir estimate. Estimated tag loss using dart tags actually resulted in a over-correction. Although these results indicate the importance of tag loss, it should be noted that the estimates were based on small sample sizes of recaptured dual tagged fish; therefore, the reliability of the estimates is somewhat low.

CONCLUSIONS

The total count of 40,282 adult sockeye salmon passing the Larson Creek weir in 1997 was slightly higher than counts from the mid 1980s, which ranged from 16,753–37,874. The ratio of these escapements to Yentna River (sonar-derived) escapements has remained fairly constant, suggesting that sonar estimates can be used to index sockeye salmon escapement in the Susitna River. The M-R experiment, which involved spaghetti tagging and spawning ground recovery surveys, showed that the combination of tag loss and tagging effects on catchability, both of which decreased the probability of recapture, can cause a major (positive) bias in the estimate of sockeye salmon escapement. Dual tagging, which corrects the tag loss problem and is often applied to 100% of marked fish, may increase this bias due to secondary tagging effects on catchability (particularly with jaw tags). The reduced probability of capture is a result of either increased mortality from handling stress or some other factor that decreases in-stream life or the availability of tagged fish to capture. Also, the nature and degree of these effects differed substantially between males and females. Unfortunately, if recovery sampling is conducted in spawning grounds this problem cannot be overcome by changing the sampling design (e.g., stratification). Therefore, the type and method of primary and secondary tagging may be critical to the success of the M-R experiment. Our preliminary experience with dart tags indicated that they are a good candidate for such applications. Alternatively, recovery sampling could take place in-stream (e.g., fishwheels) or, if the population has multiple stocks, at weirs where sampling can be controlled (i.e., every fish examined). We also found that size selectivity occurs in spawning ground surveys, indicating that a stratified design may be warranted if the first (tagging) sample is not random.

LITERATURE CITED

Anderson, T. C., and B. P. McDonald. 1978. A portable weir for counting migrating fishes in rivers. Fisheries and Marine Service Technical Report 733.

Burrows, R. E. 1963. Water temperature requirements for maximum productivity of salmon. Pages 29–38 *in* E. B. Eldridge, editor. Water temperature, influences, effects and control. Proceedings of the 12th Pacific New Symposium on Water Research. U.S. Public Health Service, Corvallis, Oregon.

Butler, J. A., and R. E. Loeffel. 1972. Comparison of retention of anchor and spaghetti tags by salmon. Pacific Marine Fisheries Commission Bulletin 8: 82–84.

Chapman, D. G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. University of California Publications in Statistics 1:131–160.

Davis, R. Z., and B. E. King 1997. Upper Cook Inlet salmon escapement studies 1996. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 2A97-23, Anchorage.

Davis, R. Z. 1998. Upper Cook Inlet salmon escapement studies 1997. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report. *In press*.

Emery, Lee. 1985. A new look at marking fish with paper fasteners, jaw tags, and cold brands. Progressive Fish-Culturalist 47:254–256.

Fleming, I. A., and M. R. Gross. 1994. Breeding competition in a Pacific salmon (Coho: *Oncorhynchus kisutch*): measures of natural and sexual selection. Evolution 48:637–657.

King, B. E., and S. C. Walker. Susitna River sockeye salmon fry studies, 1994 and 1995. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 2A97-26, Anchorage.

Koenings, J. P., J. A. Edmundson, G. B. Kyle, and J. M. Edmundson. 1987. Limnology field and laboratory manual: methods for assessing aquatic production. Alaska Department of Fish and Game, FRED Division Report Series No. 71.

Koo, T. S. Y. 1955. Biology of the red salmon, *Oncorhynchus nerka* (Walbaum), of Bristol Bay, Alaska as revealed by a study of their scales. Doctoral dissertation, University of Washington, Seattle.

MacCrimmon, H. R., and W. H. Robbins. 1979. Suitability of jaw and atkins streamer tags for marking smallmouth bass, *Micropterus dolomieui*. Transactions of the American Fisheries Society 108:499–501.

Marcuson, P. 1984. Larson Lake project progress report 1984. Cook Inlet Aquaculture Association. Soldotna, Alaska.

Marcuson, P. 1985. Larson Lake project progress report 1985. Cook Inlet Aquaculture Association. Soldotna, Alaska.

Marcuson, P. 1987. Larson Lake project progress report 1987. Cook Inlet Aquaculture Association. Soldotna, Alaska.

Marcuson, P. 1988. Larson Lake project progress report 1988. Cook Inlet Aquaculture Association. Soldotna, Alaska.

McGlennon, D., and D. Partington. 1997. Mortality and tag loss in dart and loop-tagged captive snapper, *Pagrus auratus* (Sparidae), with comparisons to relative recapture rates from a field study. New Zealand Journal of Marine and Freshwater Research 31:39–49.

McPherson, S. A., D. R. Bernard, M. S. Kelley, P. A. Milligan, and P. Timpany. 1997. Spawning abundance of chinook salmon in the Taku River in 1996. Alaska Department of Fish and Game, Division of Sport Fish, Fishery Data Series 97-14, Anchorage.

Pahlke, K. A., and D. R. Bernard. 1996. Abundance of the chinook salmon escapement in the Taku River, 1989 to 1990. Alaska Fishery Research Bulletin 3(1):9–20.

Quinn, T. P., and C. J. Foote. 1994. The effects of body size and sexual dimorphism on the reproductive behaviour of sockeye salmon, *Oncorhynchus nerka*. Animal Behavior 48:751–761.

Ruesch, P. H., and J. Fox. 1997. Upper Cook Inlet commercial fisheries annual management report, 1996. Alaska Department of Fish and Game, Commercial Fisheries Management and Development Division, Regional Information Report 2A97-16, Anchorage.

Schroder, S. L. 1981. The influence of intrasexual competition on the distribution of chum salmon in an experimental stream. Pages 275–285 *in* E. L. Brannon and E. O. Salo, editors. Salmon and trout migratory behavior symposium. University of Washington, Seattle.

Seber, G. A. F. 1970. The effects of tag response on tag-recapture estimates. Biometrika 26:12–22.

Seber, G. A. F. 1982. The estimation of animal abundance and related parameters, 2nd edition. Charles Griffin and Company Ltd., London.

Slatick, E. 1976. Comparative retention of dart and jaw tags on chinook salmon and steelhead trout during their spawning migration. Marine Fisheries Review 38:24–26.

Slatick, E., and L. Basham. 1984. Nonselectivity of gillnet fishery on jaw-tagged adult steelhead, *Salmo gairdneri*. Marine Fisheries Review 46:68–70.

Sprankle, K., J. Boreman, and J. B. Hestbeck. Loss rates for dorsal loop and internal anchor tags applied to striped bass. 1996. North American Journal of Fisheries Management 16:461–464.

Thompson, F.M., S.N. Wick, and B.L. Stratton. 1986. Susitna River Aquatic Studies Program. Adult Salmon Investigations: May–October 1985. Alaska Department of Fish and Game Report No. 13, Vol. I.

Timmons, T. J., and M. H. Howell. 1995. Retention of anchor and spaghetti tags by paddlefish, catfishes, and buffalo fishes. North American Journal of Fisheries Management 15:504–506.

Tobias, T. M., D. L. Waltemyer, and K. E. Tarbox. 1994. Scale aging manual for Upper Cook Inlet sockeye salmon. Alaska Department of Fish and Game, Division of Commercial Fisheries Management and Development, Regional Information Report 2A94-36, Anchorage.

Table 1. Daily counts and tagging schedule of adult sockeye salmon passing Larson Creek weir in 1997. See text for a description of tagging methods.

Date	Daily Count	Cumulative Total	Untagged	Spaghetti Tag Count	Spaghetti Tag Color	Secondary Tag Jaw	Secondary Tag Clip	Secondary Tag Dart
21-Jul	495	495	490	5	Orange	3		
22-Jul	168	663	164	4		3		
23-Jul	24	687	24	0		0		
24-Jul	395	1,082	351	44		11		
25-Jul	849	1,931	822	27		6		
26-Jul	23	1,954	9	14		6		
27-Jul	1,258	3,212	1,176	82		20		
28-Jul	2,159	5,371	2,098	61		10		
29-Jul	1,182	6,553	1,141	41		5		
30-Jul	1,697	8,250	1,669	28		7		
31-Jul	1,311	9,561	1,156	119		23		
				36	Yellow	15	36	
1-Aug	398	9,959	262	136		30	136	
2-Aug	426	10,385	335	91		21	91	
3-Aug	443	10,828	423	20		5	20	
4-Aug	1,176	12,004	1,060	116		29	116	
5-Aug	1,759	13,763	1,596	101		25	101	62
				62	Pink	15		
6-Aug	1,135	14,898	1,004	131		33		131
7-Aug	1,027	15,925	919	108		27		57
8-Aug	812	16,737	715	97		24		
9-Aug	1,081	17,818	979	102		26		
10-Aug	1,190	19,008	1,071	119	Blue	29		
11-Aug	1,083	20,091	973	110		28		
12-Aug	1,279	21,370	1,152	127		32		
13-Aug	401	21,771	357	44		11		
14-Aug	300	22,071	270	30		7		
15-Aug	559	22,630	503	56		14		
16-Aug	277	22,907	246	14		4		
				17	White	4		
17-Aug	264	23,171	238	26		6		
18-Aug	597	23,768	540	57		15		
19-Aug	964	24,732	868	96		24		
20-Aug	999	25,731	906	93		22		
21-Aug	612	26,343	551	61		15		

Table 1 (continued)

Date	Daily Count	Cumulative Total	Untagged	Spaghetti Tag Count	Spaghetti Tag Color	Secondary Tag Jaw	Secondary Tag Clip	Secondary Tag Dart
22-Aug	1,504	27,847	1,354	150		38		
23-Aug	453	28,300	410	43	Green	10		
24-Aug	1,111	29,411	1,004	107		27		
25-Aug	2,002	31,413	1,804	198		50		
26-Aug	1,591	33,004	1,433	103		38		
				55	Gray	3		
27-Aug	1,567	34,571	1,417	150		41		
28-Aug	1,291	35,862	1,149	142		47		
29-Aug	1,165	37,027	1,049	116		29		
30-Aug	759	37,786	681	78		20		
31-Aug	517	38,303	466	6		0		
				45	Brown	12		
1-Sep	304	38,607	274	30		7		
2-Sep	197	38,804	175	22		6		
3-Sep	140	38,944	126	14		4		
4-Sep	201	39,145	181	20		5		
5-Sep	282	39,427	254	28		7		
6-Sep	301	39,728	271	30		7		
7-Sep	88	39,816	78	10		3		
8-Sep	240	40,056	226	14		2		
9-Sep	74	40,130	57	17		5		
10-Sep	33	40,163	30	3		0		
11-Sep	48	40,211	45	3		1		
12-Sep	44	40,255	40	4		2		
13-Sep	27	40,282	27	0		0		
Total	40,282		36,619	3,663		919	500	250
% Tagged				9.09%		2.28%	1.24%	0.62%

Table 2. Estimates of sex composition and abundance, and mean mid-eye to tail fork length (MEF) of adult sockeye salmon passing the Larson Creek weir in 1997. Sample sizes were 2,082 females and 1,658 males. Standard errors (SE) and 95% confidence intervals are given.

				95% C. I.	
Variable	Sex	Estimate	SE	Lower	Upper
Composition	Female	55.7%	0.77%	54.2%	57.2%
	Male	44.3%	0.77%	42.8%	45.8%
Abundance	Female	22,439	312	21,828	23,049
	Male	17,843	312	17,233	18,454
Mean MEF (mm)	Female	493	0.7	492	494
	Male	530	1.1	528	532
	Both	509	0.7	508	510

Table 3. Age composition estimates of adult sockeye salmon passing the Larson Lake weir in 1997 ($n = 357$). Standard errors (SE) and 95% confidence intervals are also given.

				95% C. I.	
Age	*n*	Percent	SE	Lower	Upper
1.2	191	53.5%	2.6%	48.4%	58.6%
1.3	129	36.1%	2.5%	31.2%	41.0%
2.2	13	3.6%	1.0%	1.6%	5.6%
2.3	24	6.7%	1.3%	4.2%	9.2%

Table 4. Summary of first-time captures of adult sockeye salmon, by sampling period and area, from spawning ground surveys of Larson Lake in 1997. Sampling periods were: (1) 8/21 to 8/27; (2) 8/28 to 9/10; (3) 9/02 to 9/06; (4) 9/07 to 9/11; (5) 9/12 to 9/16; (6) 9/17 to 9/21; (7) 9/22 to 9/25; and (8) 9/26 to 9/27. Area codes (see Figure 3) are: EB=east beach; IN=inlet; NEB= northeast beach; OUT=outlet; SBE=south beach east; and SEB=southeast beach.

		Untagged			Tagged (recoveries)			Total Captures		
Period	Area	female	male	total	female	male	total	female	male	total
1	EB	26	40	66	1	7	8	27	47	74
	IN	51	51	102	5	10	15	56	61	117
	NEB	74	79	153	5	6	11	79	85	164
	OUT	0	0	0	0	0	0	0	0	0
	SBE	11	24	35	0	1	1	11	25	36
	SEB	294	307	601	21	11	32	315	318	633
2	EB	19	16	35	0	1	1	19	17	36
	IN	63	44	107	8	2	10	71	46	117
	NEB	59	66	125	6	8	14	65	74	139
	OUT	8	7	15	1	1	2	9	8	17
	SBE	23	26	49	1	0	1	24	26	50
	SEB	259	223	482	13	14	27	272	237	509
3	EB	35	40	75	4	5	9	39	45	84
	IN	86	73	159	18	8	26	104	81	185
	NEB	69	72	141	16	12	28	85	84	169
	OUT	88	101	189	4	10	14	92	111	203
	SBE	92	102	194	13	8	21	105	110	215
	SEB	240	172	412	14	11	25	254	183	437
4	EB	104	110	214	4	4	8	108	114	222
	IN	45	25	70	3	4	7	48	29	77
	NEB	128	105	233	3	3	6	131	108	239
	OUT	92	101	193	11	15	26	103	116	219
	SBE	103	76	179	4	5	9	107	81	188
	SEB	335	215	550	18	20	38	353	235	588
5	EB	47	28	75	1	1	2	48	29	77
	IN	11	4	15	0	0	0	11	4	15
	NEB	78	70	148	2	5	7	80	75	155
	OUT	159	151	310	9	15	24	168	166	334
	SBE	117	78	195	2	4	6	119	82	201

Table 4 (continued)

Period	Area	Untagged			Tagged (recoveries)			Total Captures		
		female	male	total	female	male	total	female	male	total
	SEB	170	116	286	11	7	18	181	123	304
6	EB	79	54	133	5	2	7	84	56	140
	IN	0	1	1	1	0	1	1	1	2
	NEB	89	76	165	0	0	0	89	76	165
	OUT	95	82	177	5	7	12	100	89	189
	SBE	61	50	111	3	6	9	64	56	120
	SEB	276	184	460	17	11	28	293	195	488
7	EB	52	51	103	2	0	2	54	51	105
	IN	0	0	0	0	0	0	0	0	0
	NEB	104	69	173	10	5	15	114	74	188
	OUT	70	58	128	2	3	5	72	61	133
	SBE	63	41	104	9	1	10	72	42	114
	SEB	136	123	259	14	2	16	150	125	275
8	EB	38	30	68	2	2	4	40	32	72
	IN	0	0	0	0	0	0	0	0	0
	NEB	48	37	85	3	0	3	51	37	88
	OUT	37	37	74	6	2	8	43	39	82
	SBE	30	12	42	1	0	1	31	12	43
	SEB	80	69	149	7	6	13	87	75	162
	Total	**4,144**	**3,496**	**7,640**	**285**	**245**	**530**	**4,429**	**3,741**	**8,170**

Table 5. Comparison of sex composition and mean mid-eye to tail fork length (MEF) of adult sockeye salmon sampled in 1997 at Larson Creek weir and in spawning ground surveys of the lake (untagged fish). Sex composition did not differ significantly between the samples ($\chi^2 = 1.7$; $P = 0.19$). However, the mean MEF of males and females was significantly greater at the weir than in the spawning grounds ($P < 0.001$, both sexes).

			Composition (%)		MEF (mm)	
Sample	Sex	*n*	Estimate	SE	Mean	SE
Weir	Female	2085	55.7%	0.77%	493	0.74
	Male	1658	44.3%		530	1.05
Survey	Female	4032	54.4%	0.58%	485	0.50
	Male	3379	45.6%		511	0.63

Table 6. Comparison of sex composition and mean mid-eye to tail fork length (MEF) of adult sockeye salmon tagged in 1997 at Larson Creek weir and recaptured in spawning grounds. For all tagged fish, sex composition did not differ between those tagged and recaptured ($\chi^2 = 1.1$; $P = 0.29$). Similar results were obtained for fish fitted only with spaghetti tags ($\chi^2 = 0.34$; $P = 0.56$). Mean MEF did not differ significantly between tagged and recaptured females (t-test; $P > 0.10$) and again similar results were obtained for both tag groups. However, the mean MEF of tagged males was significantly greater than recaptured males (t-test ; $P < 0.001$) and again results were similar between tag groups.

				Composition		MEF (mm)	
Tag Group	Sample	Sex	n	Estimate	SE	Mean	SE
All Spaghetti	Tagged	Female	1801	56.1%	0.84%	493	0.81
		Male	1412	43.9%		532	1.16
	Recaptured	Female	285	53.8%	2.17%	490	1.82
		Male	245	46.2%		518	2.18
Spaghetti Only	Tagged	Female	1224	56.6%	1.04%	492	0.97
		Male	940	43.4%		530	1.43
	Recaptured	Female	216	55.0%	2.51%	488	2.04
		Male	177	45.0%		518	2.61

Table 7. Untagged captures and recoveries of all tagged sockeye salmon, by period and area, from Larson Lake spawning ground surveys in 1997. Chi-square tests indicated temporal differences in the proportion of tagged fish for both sexes ($P < 0.05$). However, after removing period 3 from the analysis, no differences were detected for either sex ($P > 0.05$). Areal differences in the tagged proportion were also detected ($P < 0.05$), although after removing Inlet area samples from the analysis, no differences were detected for either sex ($P > 0.05$). The proportion of recovered tags did not differ between males and females ($P = 0.83$). Data reported is for first-time captures.

	Untagged Captures			Tag Recoveries			Tagged Proportion		
Stratum	Female	Male	Total	Female	Male	Total	Female	Male	Total
Period:									
(1) 8/21-8/27	456	501	957	32	35	67	6.6%	6.5%	6.5%
(2) 8/28-9/01	431	382	813	29	26	55	6.3%	6.4%	6.3%
(3) 9/02-9/06	610	560	1170	69	54	123	10.2%	8.8%	9.5%
(4) 9/07-9/11	807	632	1439	43	51	94	5.1%	7.5%	6.1%
(5) 9/12-9/16	582	447	1029	25	32	57	4.1%	6.7%	5.2%
(6) 9/17-9/21	600	447	1047	31	26	57	4.9%	5.5%	5.2%
(7) 9/22-9/25	425	342	767	37	11	48	8.0%	3.1%	5.9%
(8) 9/26-9/27	233	185	418	19	10	29	7.5%	5.1%	6.5%
Area:									
East Bch.	400	369	769	19	22	41	4.5%	5.6%	5.1%
Inlet	256	198	454	35	24	59	12.0%	10.8%	11.5%
Northeast Bch.	649	574	1223	45	39	84	6.5%	6.4%	6.4%
Outlet	549	537	1086	38	53	91	6.5%	9.0%	7.7%
South Bch. E.	500	409	909	33	25	58	6.2%	5.8%	6.0%
Southeast Bch.	1,790	1,409	3,199	115	82	197	6.0%	5.5%	5.8%
Total - all data	3,744	3,127	6,871	285	245	530	7.1%	7.3%	7.2%
Total - w/o period 3	3,534	2,936	6,470	216	191	407	5.8%	6.1%	5.9%
Total - w/o Inlet	3,239	2,724	5,963	205	182	387	6.0%	6.3%	6.1%

Table 8. Untagged captures and recaptures, by stratum, of sockeye salmon fitted with spaghetti tags only from Larson Lake spawning ground surveys in 1997. Chi-square tests indicated no temporal differences in the proportion of tagged male fish ($P = 0.163$). The proportion of tagged females, however, differed significantly among periods ($P = 0.009$); although, after removing period 3 from the analysis no significant differences were detected ($P = 0.07$). No areal differences were detected for either sex or the total catch ($P > 0.10$) and proportion of tagged fish did not differ between males and females ($P = 0.86$). Data reported is for first-time captures.

	Untagged Captures			Tag Recoveries			Tagged Proportion		
Stratum	Female	Male	Total	Female	Male	Total	Female	Male	Total
Period:									
(1) 8/21-8/27	456	501	957	24	25	49	5.0%	4.8%	4.9%
(2) 8/28-9/01	431	382	813	16	15	31	3.6%	3.8%	3.7%
(3) 9/02-9/06	610	560	1170	47	40	87	7.2%	6.7%	6.9%
(4) 9/07-9/11	807	632	1439	34	35	69	4.0%	5.2%	4.6%
(5) 9/12-9/16	582	447	1029	19	25	44	3.2%	5.3%	4.1%
(6) 9/17-9/21	600	447	1047	29	21	50	4.6%	4.5%	4.6%
(7) 9/22-9/25	425	342	767	30	9	39	6.6%	2.6%	4.8%
(8) 9/26-9/27	233	185	418	17	7	24	6.8%	3.6%	5.4%
Area:									
East Bch.	400	369	769	13	17	30	3.1%	4.4%	3.8%
Inlet	256	198	454	19	13	32	6.9%	6.2%	6.6%
Northeast Bch.	649	574	1223	33	33	66	4.8%	5.4%	5.1%
Outlet	549	537	1086	33	33	66	5.7%	5.8%	5.7%
South Bch. E.	500	409	909	25	21	46	4.8%	4.9%	4.8%
Southeast Bch.	1790	1409	3199	93	60	153	4.9%	4.1%	4.6%
Total - all data	3744	3127	6871	216	177	393	5.5%	5.4%	5.4%
Total - w/o Period 3	3534	2936	6470	169	137	306	4.6%	4.5%	4.5%

Table 9. Recapture fate of all tagged sockeye salmon in Larson Lake spawning ground surveys in 1997, by tagging order. Chi-square tests indicated no temporal differences ($P > 0.05$) in the proportion of tagged fish recaptured for males, females, and both sexes. The recapture rate of tagged fish also did not differ between males and females ($P = 0.31$). Data reported is for first-time captures.

Date	Tag	Not Recaptured			Recaptured			Percent Recaptured		
Tagged	Color	Female	Male	Total	Female	Male	Total	Female	Male	Total
21-Jul	Orange	164	193	357	33	35	68	16.8%	15.4%	16.0%
1-Aug	Yellow	194	232	426	39	35	74	16.7%	13.1%	14.8%
6-Aug	Pink	220	206	426	32	42	74	12.7%	16.9%	14.8%
10-Aug	Blue	232	192	424	41	35	76	15.0%	15.4%	15.2%
17-Aug	White	283	138	421	56	23	79	16.5%	14.3%	15.8%
23-Aug	Green	282	152	434	33	33	66	10.5%	17.8%	13.2%
27-Aug	Grey	247	185	432	39	29	68	13.6%	13.6%	13.6%
1-Sep	Brown	139	77	216	12	13	25	7.9%	14.4%	10.4%
Total		1,761	1,375	3,136	285	245	530	13.9%	15.1%	14.5%

Table 10. Recapture fate sockeye salmon tagged only with spaghetti tags in Larson Lake spawning ground surveys in 1997, by tagging order. Chi-square tests indicated no temporal differences ($P > 0.05$) in the proportion of tagged fish recaptured for males, females, and both sexes. The recapture rate of tagged fish also did not differ between males and females ($P = 0.56$). Data reported is for first-time captures.

Date	Tag	Not Recaptured			Recaptured			Percent Recaptured		
Tagged	Color	Female	Male	Total	Female	Male	Total	Female	Male	Total
21-Jul	Orange	126	147	273	26	32	58	17.1%	17.9%	17.5%
1-Aug	Yellow	144	167	311	35	29	64	19.6%	14.8%	17.1%
6-Aug	Pink	79	80	159	13	15	28	14.1%	15.8%	15.0%
10-Aug	Blue	170	145	315	31	29	60	15.4%	16.7%	16.0%
17-Aug	White	216	100	316	45	15	60	17.2%	13.0%	16.0%
23-Aug	Green	208	115	323	25	27	52	10.7%	19.0%	13.9%
27-Aug	Grey	180	130	310	32	18	50	15.1%	12.2%	13.9%
1-Sep	Brown	102	57	159	9	12	21	8.1%	17.4%	11.7%
Total		1,225	941	2,166	216	177	393	15.0%	15.8%	15.4%

Table 11. Results of dual tagging experiments conducted at Larson Lake in 1997. The number and percent of lost tags is given for each type of tag used in the study. The percent of fish dual tagged at the Larson Creek weir is compared with the percent of dual tagged fish recovered in the spawning grounds, after correcting for tag loss.

		Dual Tagged		Recaptures			Pred. Recaps.	
Tag Type	Sex	Total	Percent	Total	Lost	Percent	Total	Percent
Spaghetti	Female	604	2.69%	68	0	0.0%	68	1.54%
	Male	503	2.82%	69	13	21.0%	71	1.89%
	Total	1107	2.75%	137	13	10.6%	139	1.70%
Jaw	Female	503	2.24%	53	5	9.4%	53	1.20%
	Male	416	2.33%	53	5	10.4%	54	1.43%
	Total	919	2.28%	106	10	9.9%	107	1.30%
Dart	Female	126	0.56%	16	1	6.7%	16	0.36%
	Male	124	0.69%	22	2	14.3%	23	0.62%
	Total	250	0.62%	38	3	10.3%	39	0.48%

Table 12. Comparison of the proportion of sockeye salmon tagged at the Larson Creek weir (P) and the proportion of the population surveyed in the spawning grounds (E) in 1997 with mark-recapture (M-R) estimates of these parameters. Results are given for all tagged fish, spaghetti tagged only fish, and dual tagged fish (all, jaw, lower jaw, and dart). Approximate 95% confidence bounds (± 2×SE) indicated that the M-R estimates were significantly ($P < 0.05$) lower than the known or estimated values of P and E based on the weir count, even after correcting for tag loss. Variables are defined as follows: N is the weir count, m_1 is the number of fish tagged, n_2 is the number of fish sampled in the spawning grounds, and m_2 is the number of recaptures.

Tag Type	Variables				Percent Tagged		Percent Surveyed	
and Sex	N[1]	m_1	n_2	m_2	$P \pm 2(SE)$	$\hat{P} \pm 2(SE)$	$E \pm 2(SE)$	$\hat{E} \pm 2(SE)$
All Tags								
Females	22,439	2,040	4,429	285	9.1% ± 0.25%	6.4% ± 0.74%	19.7% ± 0.53%	14.0% ± 1.54%
Male	17,843	1,623	3,741	245	9.1% ± 0.31%	6.5% ± 0.81%	21.0% ± 0.71%	15.1% ± 1.78%
Total	40,282	3,663	8,170	530	9.1% na	6.5% ± 0.55%	20.3% na	14.5% ± 1.16%
Spaghetti Only								
Females	22,439	1,441	4,429	216	6.4% ± 0.17%	4.9% ± 0.65%	19.7% ± 0.53%	15.0% ± 1.88%
Male	17,843	1,118	3,741	177	6.3% ± 0.21%	4.7% ± 0.69%	21.0% ± 0.71%	15.8% ± 2.18%
Total	40,282	2,559	8,170	393	6.4% na	4.8% ± 0.47%	20.3% na	15.4% ± 1.43%
All Dual								
Females	22,439	604	4,429	68	2.7% ± 0.07%	1.5% ± 0.37%	19.7% ± 0.53%	11.3% ± 2.57%
Male	17,843	503	3,741	71	2.8% ± 0.10%	1.9% ± 0.45%	21.0% ± 0.71%	14.1% ± 3.11%
Total	40,282	1107	8,170	139	2.7% na	1.7% ± 0.29%	20.3% na	12.5% ± 1.99%
Jaw (all)								
Females	22,439	503	4,429	53	2.2% ± 0.06%	1.2% ± 0.33%	19.7% ± 0.53%	10.5% ± 2.67%
Male	17,843	416	3,741	54	2.3% ± 0.08%	1.4% ± 0.39%	21.0% ± 0.71%	12.9% ± 3.29%
Total	40,282	919	8,170	107	2.3% na	1.3% ± 0.25%	20.3% na	11.6% ± 2.11%
Lower Jaw								
Females	22,439	228	4,429	26	1.0% ± 0.03%	0.6% ± 0.23%	19.7% ± 0.53%	11.4% ± 4.22%
Male	17,843	145	3,741	24	0.8% ± 0.03%	0.6% ± 0.26%	21.0% ± 0.71%	16.7% ± 6.22%
Total	40,282	373	8,170	50	0.9% na	0.6% ± 0.17%	20.3% na	13.5% ± 3.54%
Dart								
Females	22,439	126	4,429	16	0.6% ± 0.02%	0.4% ± 0.18%	19.7% ± 0.53%	12.7% ± 5.96%
Male	17,843	124	3,741	23	0.7% ± 0.02%	0.6% ± 0.26%	21.0% ± 0.71%	18.8% ± 7.05%
Total	40,282	250	8,170	39	0.6% na	0.5% ± 0.15%	20.3% na	15.7% ± 4.61%

[1] Male and female abundances were estimated from the Larson Creek weir sample (see Table 2).

Table 13. Effect of various secondary tagging techniques on estimated spaghetti tag loss and the (corrected) mark-recapture (M-R) point estimate of the number of adult sockeye salmon passing Larson Creek weir in 1997. Corrected estimates of the number of recaptures (m_2), therefore the abundance estimates, were based on fish marked with spaghetti tags only. The percent difference is given to indicate the degree of bias in the M-R estimate compared to the weir.

		Dual	Recaptures			Corrected		Sockeye Abundance		
2^o Tag	Sex	Tagged	Count	Lost	% Lost	Count	m_2	Weir	M-R Est.	% Diff.
Jaw & Dart	Female	604	68	0	0.0%	68	216	22,439	29,437	31.2%
	Male	503	69	13	21.0%	71	224	17,843	18,613	4.3%
	Total	1107	137	13	10.6%	139	440	40,282	48,050	19.3%
All Jaw	Female	503	53	0	0.0%	53	216	22,439	29,437	31.2%
	Male	416	53	5	10.4%	54	198	17,843	21,085	18.2%
	Total	919	106	5	5.2%	107	414	40,282	50,522	25.4%
Lower Jaw	Female	228	26	0	0.0%	26	216	22,439	29,437	31.2%
	Male	145	24	5	21.7%	24	226	17,843	18,432	3.3%
	Total	373	50	5	10.4%	50	442	40,282	47,869	18.8%
Dart	Female	126	16	0	0.0%	16	216	22,439	29,437	31.2%
	Male	124	22	8	40.0%	23	295	17,843	14,145	-20.7%
	Total	250	38	8	22.9%	39	511	40,282	43,582	8.2%

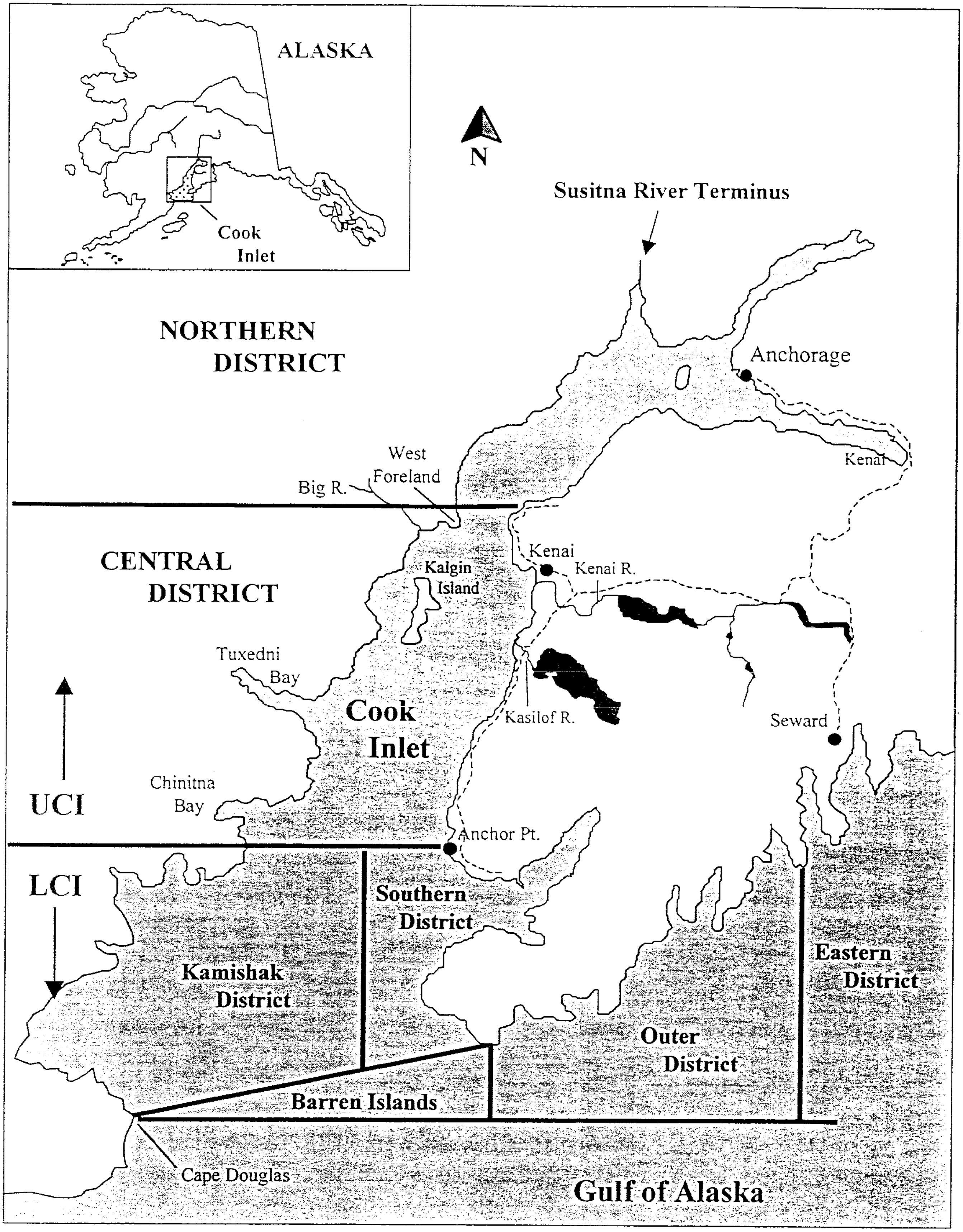

Figure 1. Upper and Lower Cook Inlet commercial fishing districts.

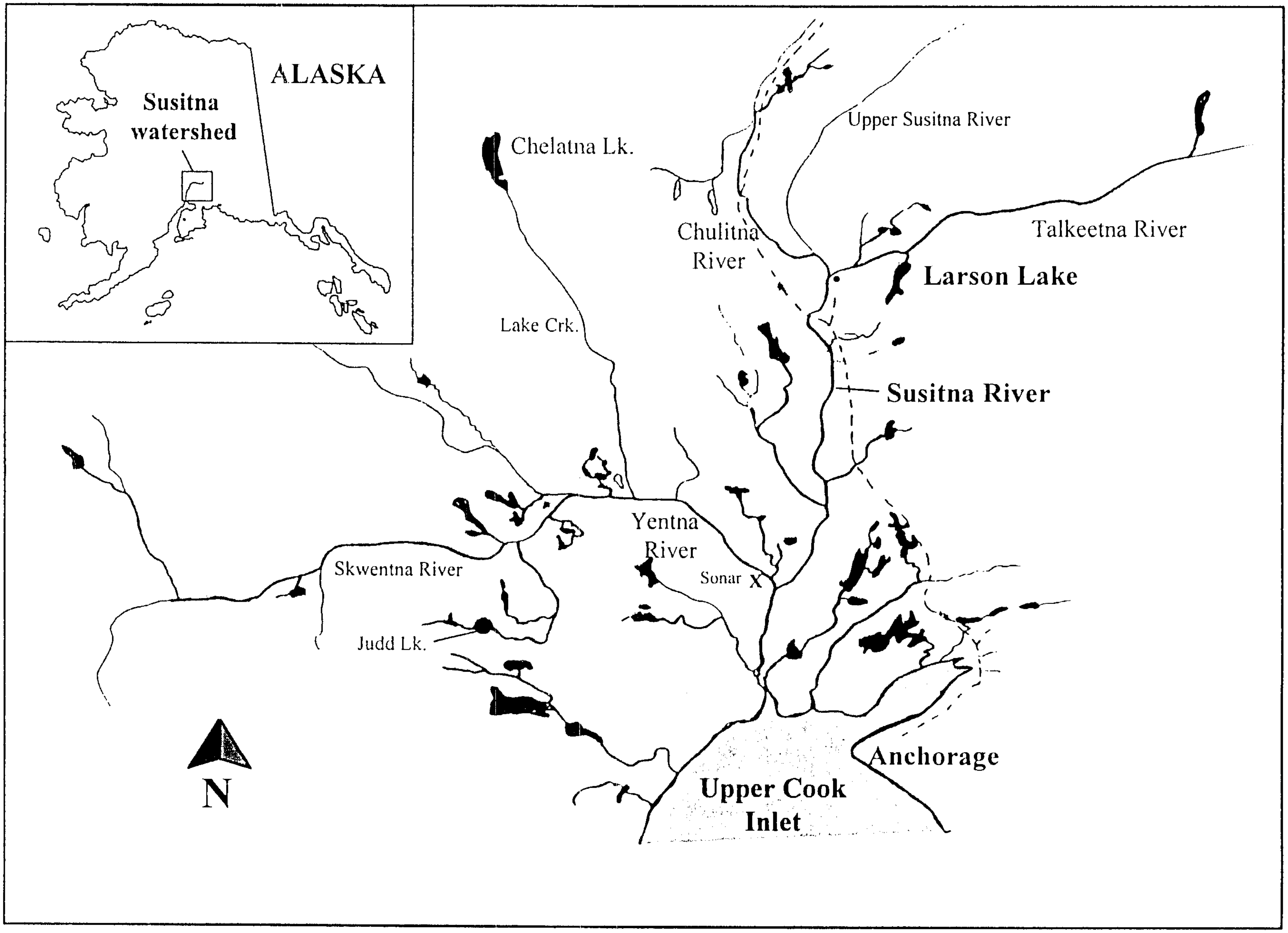

Figure 2. Location of Larson Lake within the Susitna River drainage.

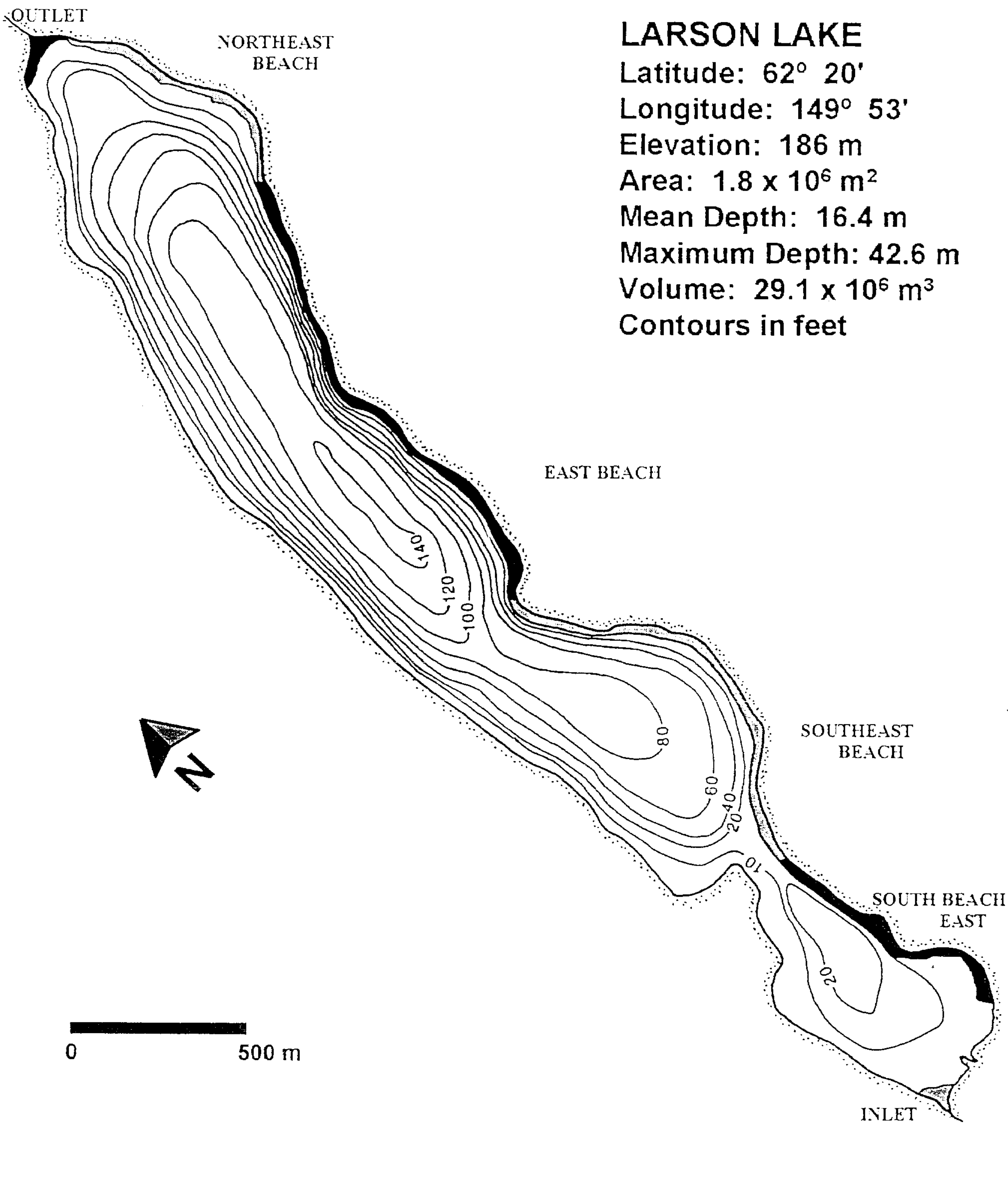

Figure 3. Bathymetric map of Larson lake showing the location of the six spawning areas surveyed for tag recoveries in 1997.

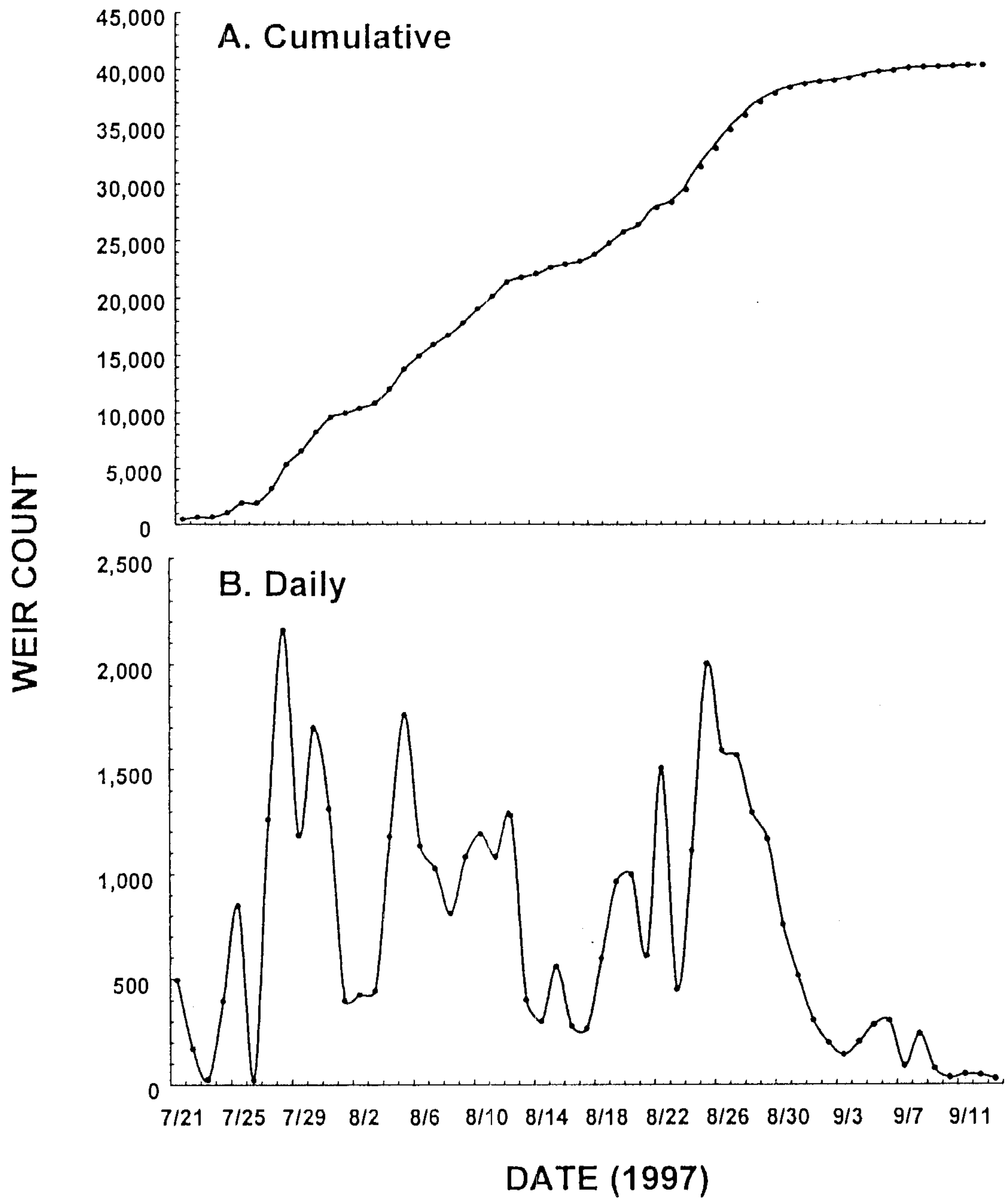

Figure 4. (A) Cumulative and (B) daily counts of adult sockeye salmon passing the Larson Creek weir in 1997.

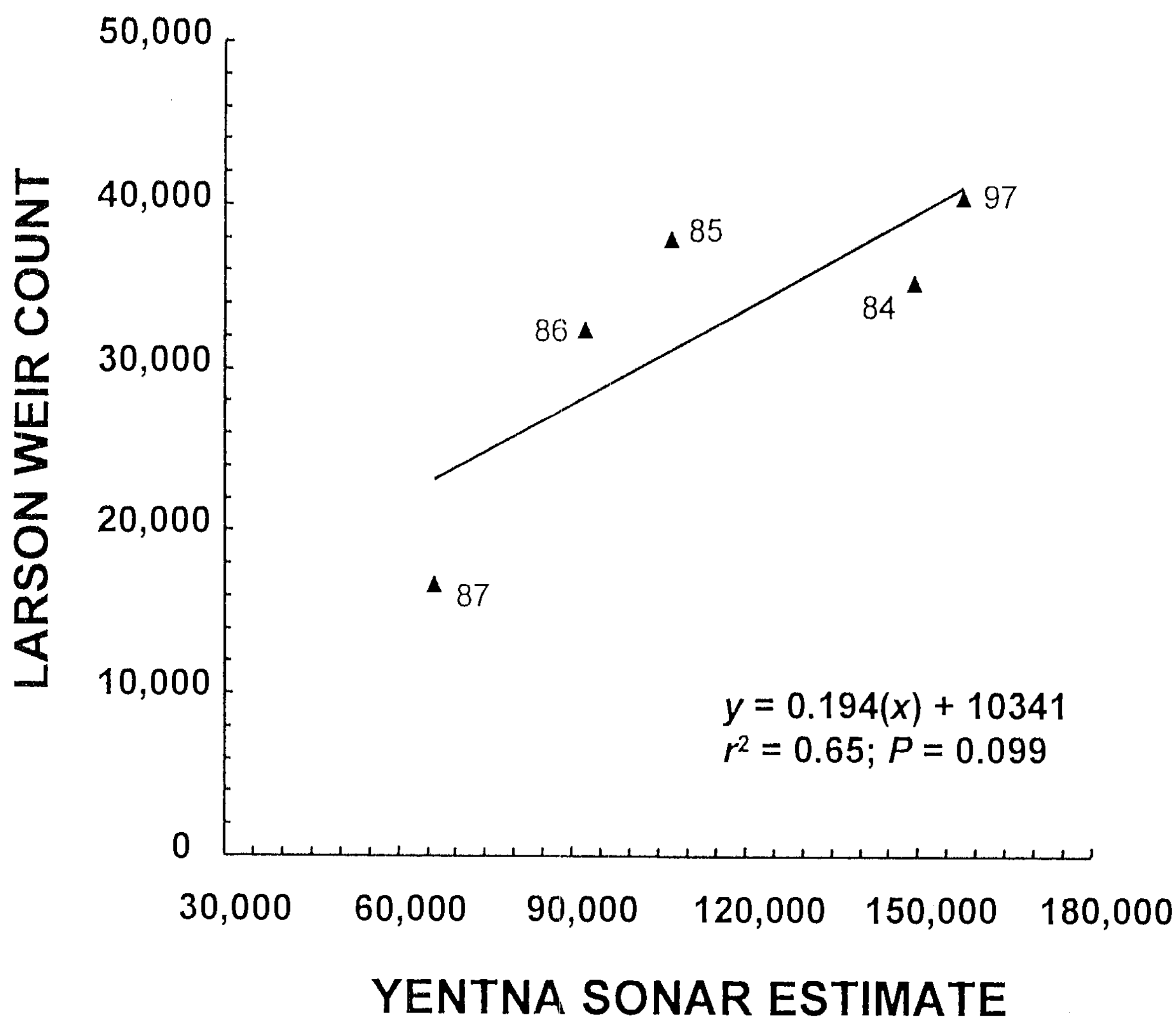

Figure 5. Relationship between Yentna River sonar abundance estimates and Larson Creek weir counts of sockeye salmon escapement ($n = 5$). Data points are labeled by year.

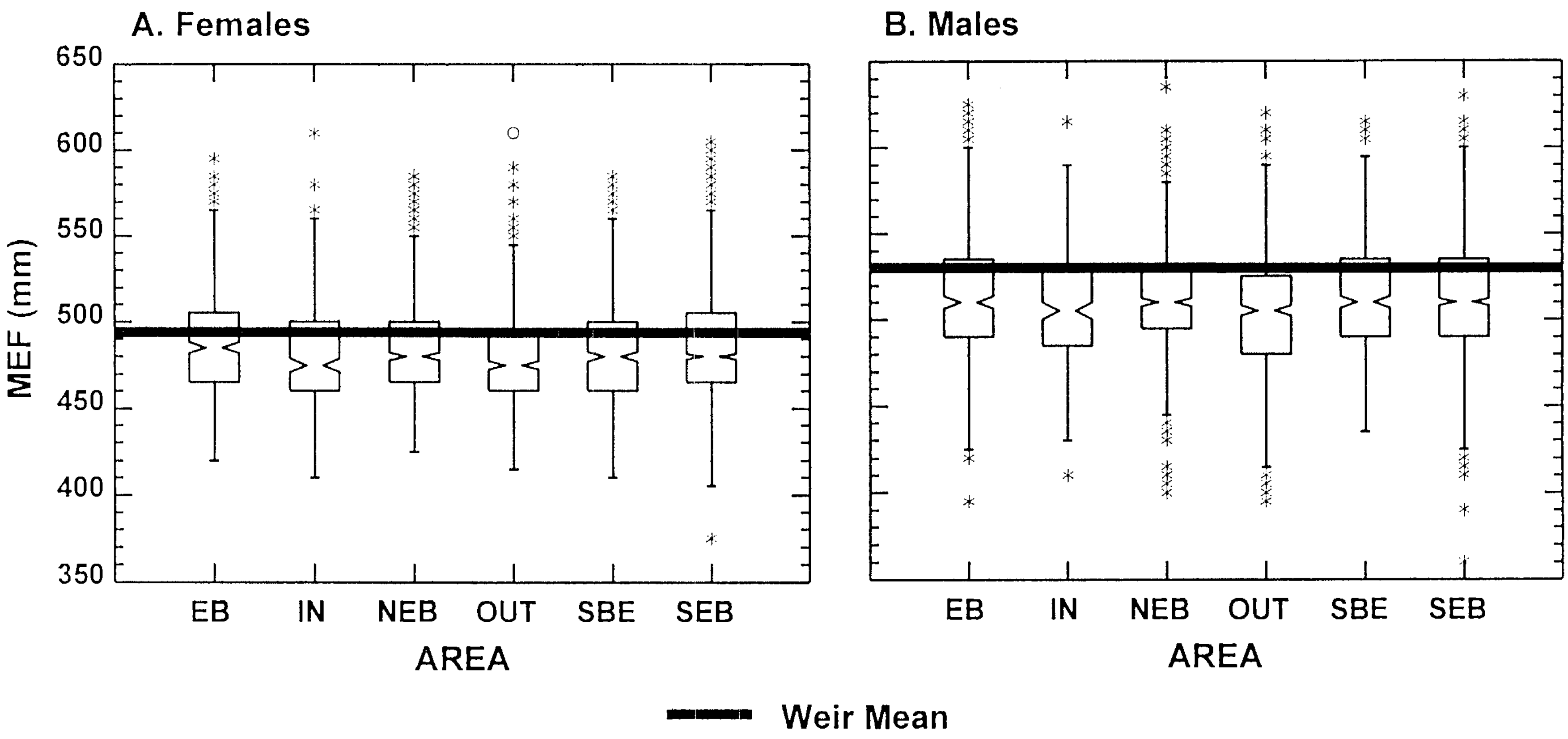

Figure 6. Box plots of mid-eye to fork length (MEF) measurements of untagged (A) female and (B) male adult sockeye salmon collected in spawning ground areas in Larson Lake in 1997. For both sexes, fish sampled from the spawning grounds were significantly ($P < 0.01$) smaller than fish sampled from the Larson Creek weir (horizontal bar). Area codes are defined as follows (see Figure 3): EB=east beach, IN=inlet, NEB=northeast beach, OUT=outlet, SBE=south beach east, and SEB=southeast beach. Width of the horizontal bar (weir mean) is the approximate 95% confidence interval.

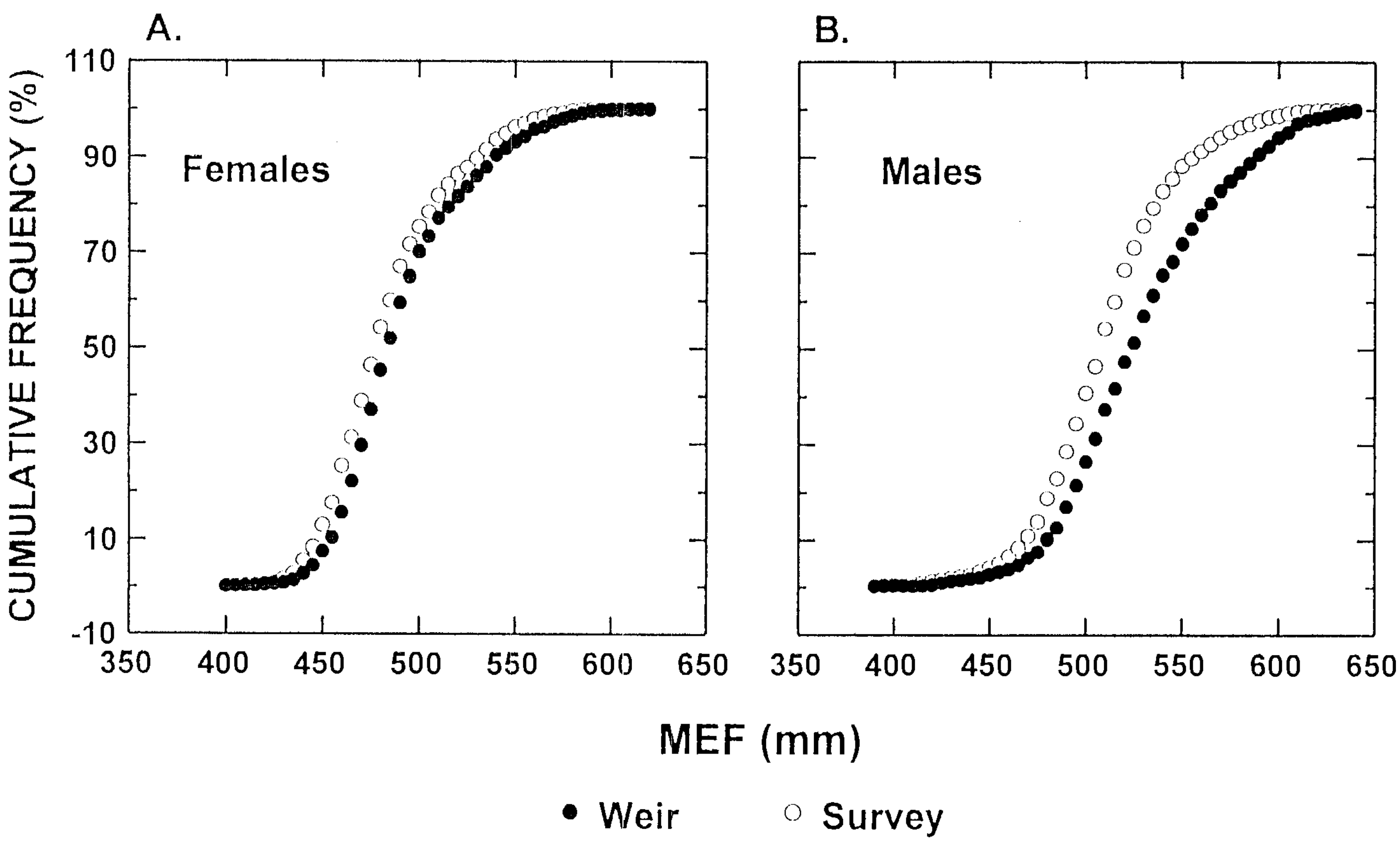

Figure 7. Comparison of distributions of sockeye salmon mid-eye to tail fork length (MEF) between the Larson Creek weir sample and spawning ground survey (seining). (A) Female MEF distributions, although similar graphically, differed significantly (K-S test; $P < 0.001$). (B) Male MEF distributions also differed significantly (K-S test; $P < 0.001$). Sample sizes were: females - 2,083 at the weir and 4,032 seined (untagged); males - 1,657 at the weir and 3,379 seined (untagged).

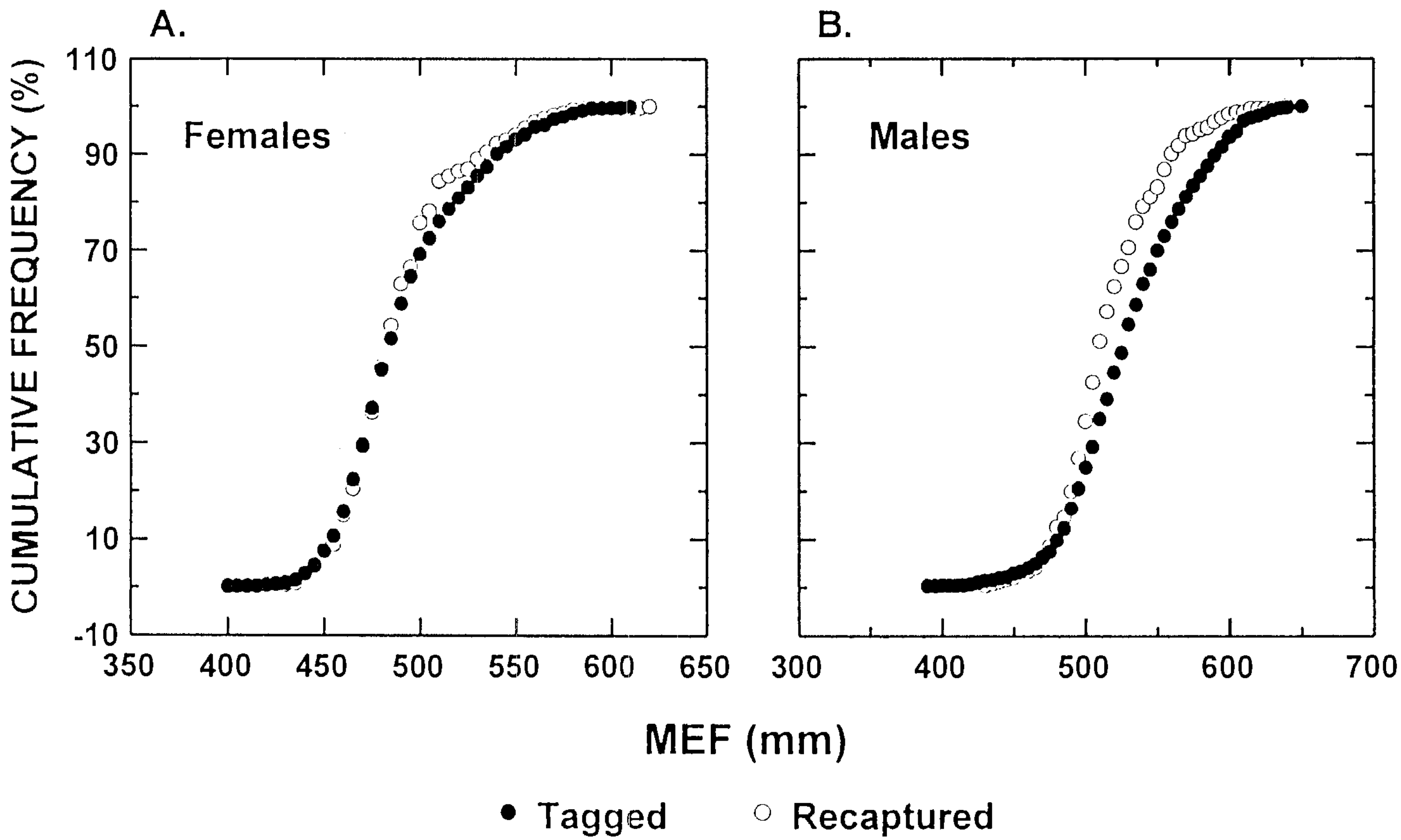

Figure 8. Comparison of distributions of sockeye salmon mid-eye to tail fork length (MEF) between fish tagged at the Larson Creek weir and recaptured in spawning grounds. (A) Female MEF distributions, although similar graphically, differed significantly (K-S test; $P = 0.007$). (B) Male MEF distributions also differed significantly (K-S test; $P < 0.001$). Sample sizes were: females - 1801 tagged (unrecovered) and 285 recaptured; males - 1412 tagged (unrecovered) and 245 recaptured. All tagged fish were used in the analysis.

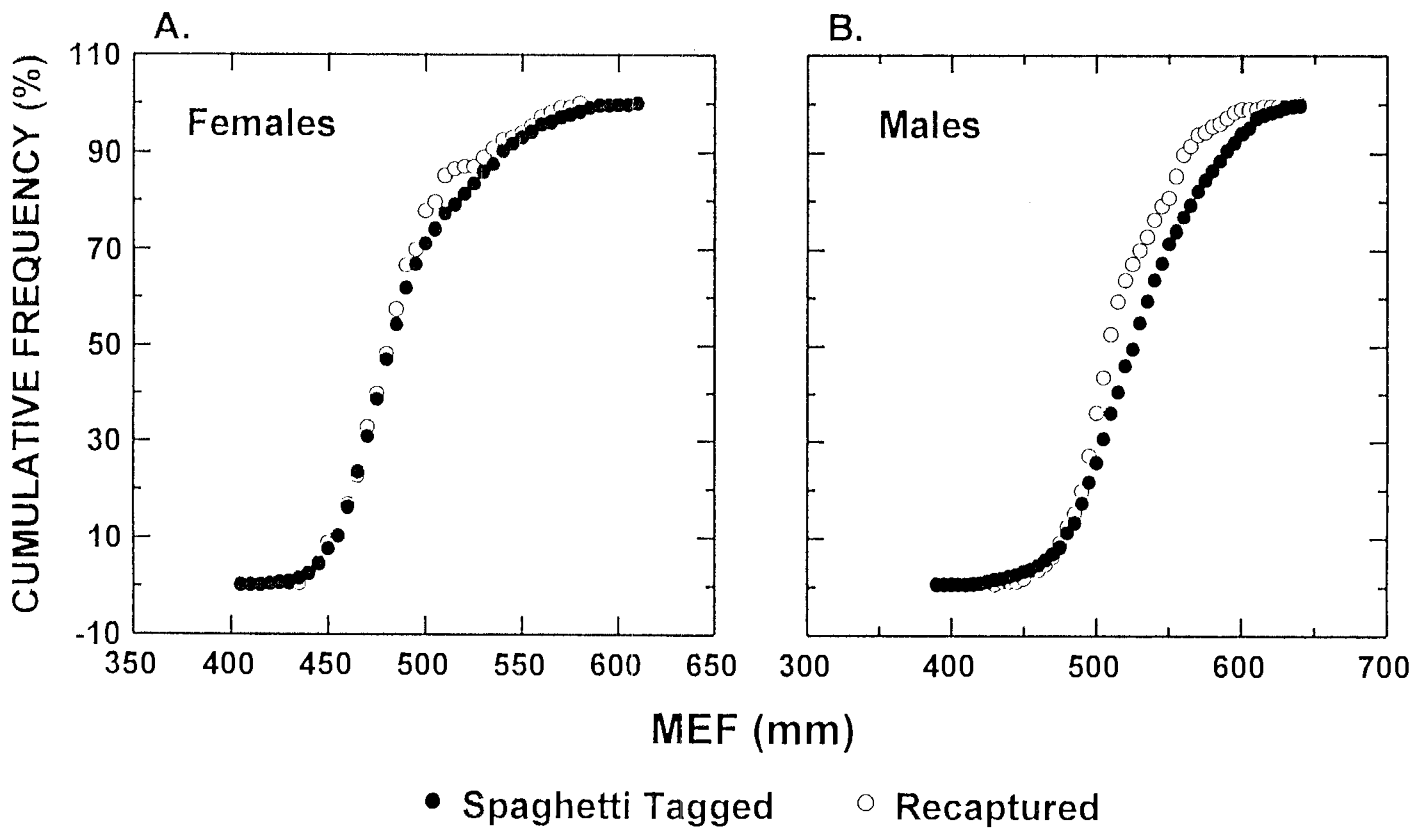

Figure 9. Comparison of distributions of sockeye salmon mid-eye to tail fork length (MEF) between fish tagged at the Larson Creek weir and recaptured in spawning grounds. Fish fitted with only a spaghetti tag were used in the analysis. (A) Female MEF distributions, although similar graphically, differed significantly (K-S test; P = 0.036). (B) Male MEF distributions also differed significantly (K-S test; $P < 0.001$). Sample sizes were: females - 1224 tagged (unrecovered) and 216 recaptured; males - 940 tagged (unrecovered) and 177 recaptured.

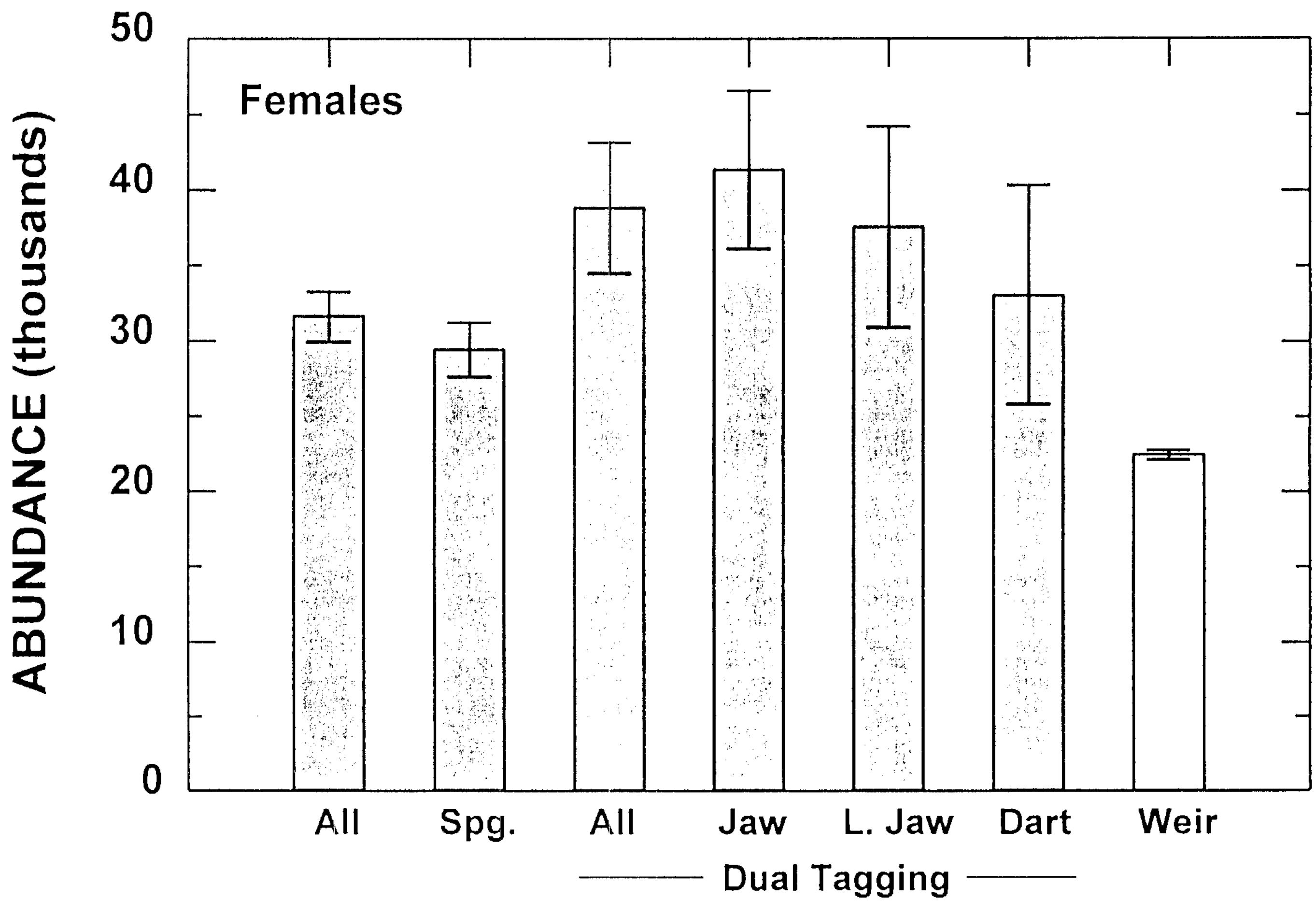

Figure 10. Mark-recapture (M-R) abundance estimates of adult sockeye salmon females passing the Larson Creek weir in 1997. M-R Estimates (gray bars) and approximate 95% confidence intervals (vertical line at bar top) are given for all tagged fish, spaghetti tagged only fish, and dual tagged fish (all, jaw, lower jaw, and dart). The weir estimate (white bar), which was based on a total count of the population ($N = 40{,}282$), is shown for comparative purposes. The M-R estimates were all significantly greater ($P < 0.05$) than the weir estimate, ranging from 31-84% higher.

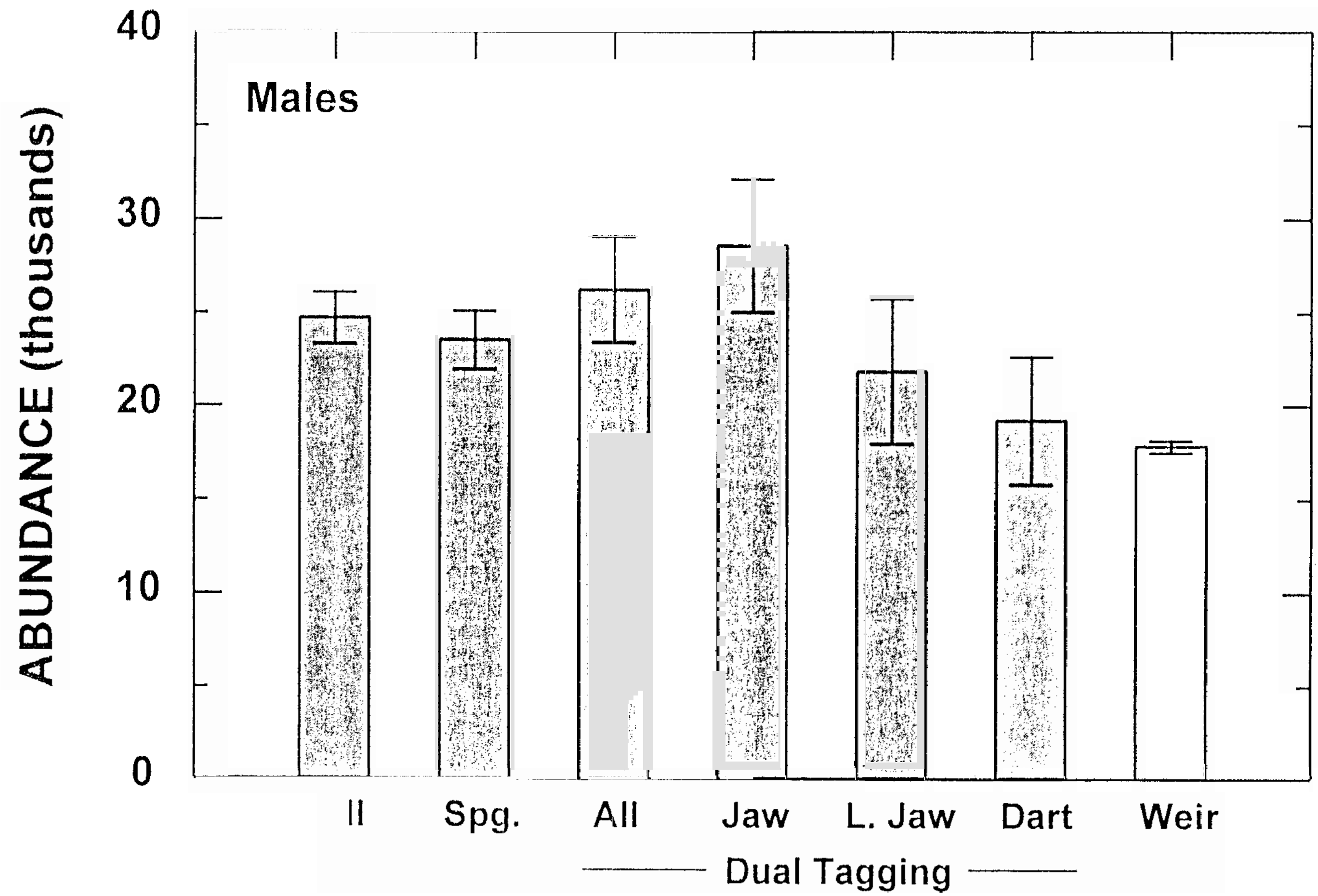

Figure 11. Mark-recapture (M-R) abundance estimates of adult sockeye salmon males passing the Larson Creek weir in 1997. M-R Estimates (gray bars) and approximate 95% confidence intervals (vertical line at bar top) are given for all tagged fish, spaghetti tagged only fish, and dual tagged fish (all, jaw, lower jaw, and dart). The weir estimate (white bar), which was based on a total count of the population (N = 40,282), is shown for comparative purposes. The M-R estimates from lower jaw and dart tagging did not differ significantly ($P >$ 0.05) from the weir estimate. The remaining M-R estimates were all significantly greater ($P < 0.05$) than the weir estimate, ranging from 32-60% higher.

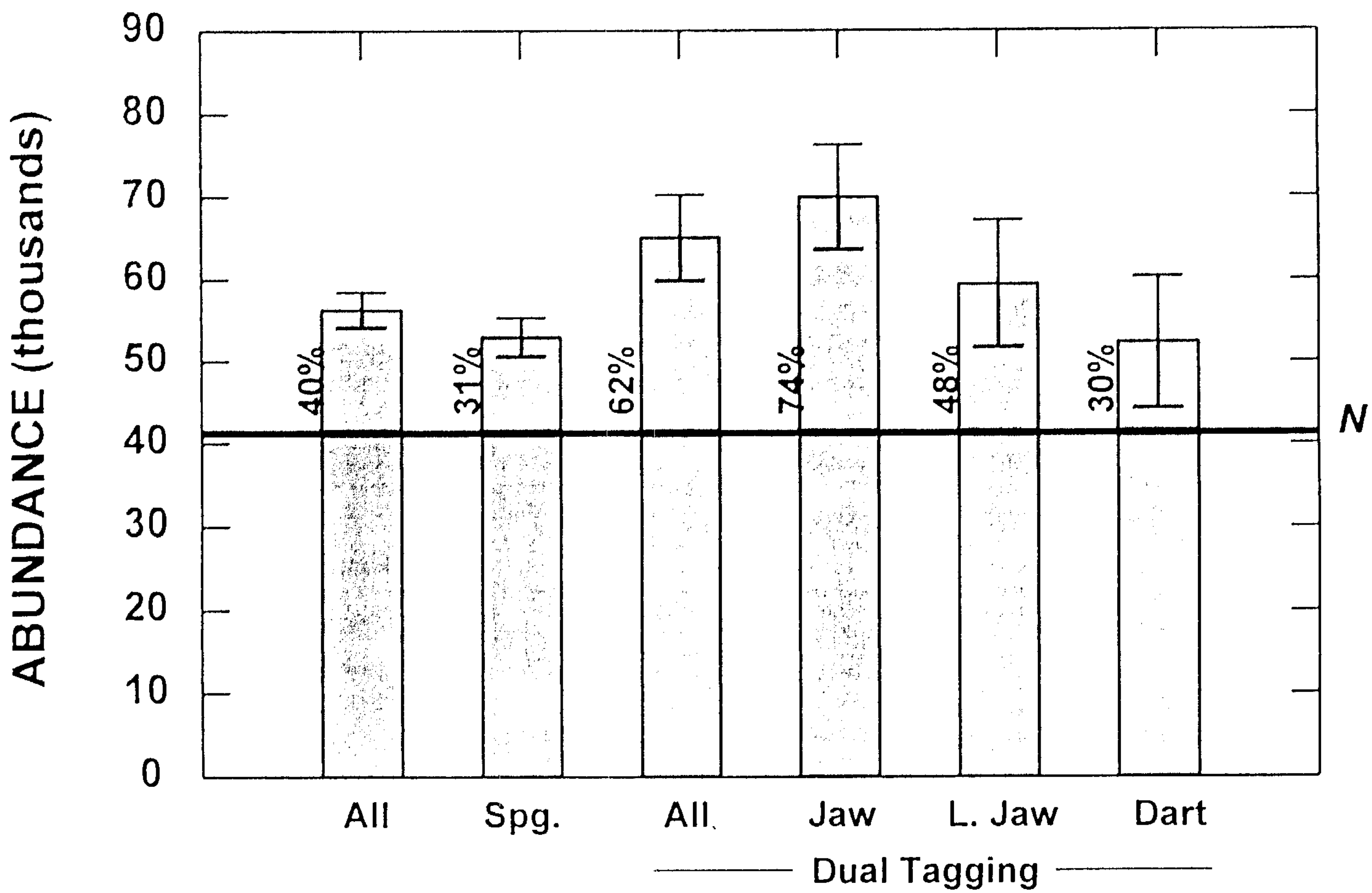

Figure 12. Mark-recapture (M-R) abundance estimates of adult sockeye salmon passing the Larson Creek weir in 1997. M-R Estimates and approximate 95% confidence intervals (vertical line at top of bar) are given for all tagged fish, spaghetti tagged only fish, and dual tagged fish (all, jaw, lower jaw, and dart). The total weir count (N = 40,282), indicated by the horizontal line, is shown for comparative purposes. All of the total M-R estimates were significantly greater ($P < 0.05$) than the weir count. The percent error in the point estimate is given next to each bar.